Electric Lighting

AND

Power Distribution.

VOLUME I.

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FIFTH EDITION.

W. PERREN MAYCOCK, M.I.E.E.

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ELECTRIC LIGHTING

AND

POWER DISTRIBUTION.

FIFTH EDITION.

VOL. I.

o

ELECTRIC LIGHTING AND POWER DISTRIBUTION.

AN ELEMENTARY MANUAL OF ELECTRICAL ENGINEERING

SUITABLE FOR

STUDENTS PREPARING FOR THE PRELIMINARY AND ORDINARY GRADE EXAMINATIONS OF THE CITY AND GUILDS OF LONDON INSTITUTE.

BY

W. PERREN MAYCOCK, M.I.E.E.

FIFTH AND REVISED EDITION.

(IN TWO VOLUMES)

VOL. I.

With numerous questions and exercises, including all those set for the Preliminary and Ordinary Grade Examinations since 1890.

229 Illustrations, Index, and Ruled Pages for Notes.

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1902.

PREFACE TO THE FIFTH EDITION.

(Vol. I.)

In this Edition, Chapter IX. has been almost entirely re-written, and thereby brought up to date; while a few corrections and minor alterations have been made in most of the others. The Examination Questions up to last year have been included.

W. P. M.

Waddon, Surrey.
February, 1902.

EXTRACT FROM PREFACE (FOURTH EDITION).

(Vol. I.)

I did not anticipate that a new issue of Vol. I. would be required before Vol. II. saw the light; but such is the case, and I feel I owe an apology to my readers for the delay with the latter. However, I may point out, in part extenuation, that a recent book—*The Alternating-Current Circuit*—and one about to be published—*Electric Wiring, Fittings, Switches, and Lamps*—are really portions of Vol. II. published in advance.

W. P. M.

"Milber," Waddon, Surrey.
May, 1898.

EXTRACT FROM PREFACE (THIRD EDITION).

(Vol. I.)

This Third Edition of a work which first made its appearance at the end of 1892, and which has been most favourably received by both teachers and students, is practically a new book. It has been entirely re-written, and supplied with a great many new illustra-

tions; the chief additions in Vol. I. being Chap. V. on Electric Bell Fitting, and Chap. VI. on the Magnetisation of Iron.

To Mr. Charles H. Yeaman I am deeply indebted for much valuable help in the writing of the work, and in the revision of both MS. and proofs; and I beg to offer him my very sincere thanks.

Most of the new drawings have been executed by Mr. H. L. Mills.

Though this work will, I trust, be found really elementary so far as regards the technics of Electric Lighting and Power Distribution, the reader is expected to have some acquaintance with the fundamental principles of the science of Electricity and Magnetism, such, for instance, as is afforded by my *First Book of Electricity and Magnetism.*

Paragraphs 130, 133, and 134, relating to the Swinburne Instruments, recently appeared as a series of articles by me in the *Electrical Engineer.*

In spite of the very careful revision to which the work has been subjected, there may possibly be some errors; and there are sure to be various points on which differences of opinion exist, or which are not clearly dealt with. Of these I shall be most thankful for intimation from any of my readers.

W. P. M.

"Milber," Waddon, Surrey.
April, 1896.

EXTRACT FROM PREFACE (FIRST EDITION).

I am much indebted to Mr. James Swinburne, M.I.E.E., for giving me the benefit of his experience by revising the proofs, and making many valuable suggestions.

W. P. M.

"Milber," Waddon, Surrey.
October, 1892.

VOLUME I.

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The figures refer to the numbered paragraphs.

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[*NOTE.*—VOLUME II. will comprise chapters on the Theory and Working of Dynamos, Alternating Currents, Alternators, Motors, Meters, Accumulators, Transformers, and Central Stations. It was intended to include in this the already published *Electric Wiring, Fittings, Switches, and Lamps*, but owing to the bulk of the latter, it has now been decided to keep it as a separate and supplementary Volume.]

LIST OF ILLUSTRATIONS AND DIAGRAMS.

NOTES.

1. Students preparing for the *Preliminary Examination* of the City and Guilds of London Institute need only read those paragraphs which are marked by asterisks. Questions relating to the Preliminary syllabus are similarly distinguished.

2. Ordinary Grade Students may omit passages in small type on a first reading.

ELECTRIC LIGHTING AND POWER DISTRIBUTION.

AN ELEMENTARY MANUAL OF ELECTRICAL ENGINEERING.

VOLUME I. (5th EDITION).

CHAPTER I.

The figures refer to the numbered paragraphs.

* 1. **Force.** *Force is that which produces or tends to produce motion or change of motion of matter.* When a body is set in motion it is because a *force* has been applied to it. In order to increase or decrease the motion of a moving body, or to stop it, it is necessary to apply force.

Take, for example, a garden roller upon a smooth level path. To produce motion of the roller it is necessary to apply force, either by pushing or pulling at the

handle. When once the roller is in motion, it is comparatively easy to keep it moving. To make it go faster or slower, *i.e.*, to change its motion, it is necessary to apply extra force. To stop it suddenly when in motion, *i.e.*, to change its motion from something to nothing, a good deal of force must be exerted.

Force does not always produce motion. Suppose, for example, that a man tries to move a heavily-laden railway truck standing upon a line: he might exert all the force of which he is capable without moving the truck an inch. This would be a case of force tending to produce motion. The man could not move the railway truck, because he is not capable of applying sufficient force to it. An engine, being able to exert very much more force, could move the truck with ease. As another case in which force tends to but does not produce motion, let us suppose a train of railway trucks standing on a line, with an engine at each end, one pushing one way and one the other. If the engines exert equal forces, their driving wheels will merely slip round without producing any motion of the train.

* 2. DIFFERENT KINDS OF FORCE. There are different kinds of force. First of all there is the *force of gravitation*, in virtue of which bodies will fall from a higher level to a lower whenever able. The force which a man exerts when he lifts a heavy body or knocks another man down, is *muscular force.* The force which a horse exerts in drawing a carriage is muscular force. The force which a steam engine

exerts is *mechanical force*, due in the first instance to the force of expansion of the steam upon the piston. We have an example of *chemical force* when a mixture of coal-gas and air in a room is ignited, and the resulting explosion blows out the windows. *Electromotive-force* is a force producing or tending to produce a flow of electricity (§§ 27, 30, 45, etc.): and *magnetomotive-force*[1] is a force which produces magnetism, *i.e.*, it sets up magnetic lines (§§ 90, 92).

The amount of motion produced in a train, for instance, *i.e.*, the rate at which it moves along the line, depends upon the force exerted by the engine. Similarly, the rate of "flow of electricity" (the resistance of the circuit remaining constant,) depends upon the electromotive force: and the number of magnetic lines set up depends upon the magnetomotive-force.

The term magnetomotive-force refers to the magnetic effect of a current of electricity flowing round a coil or coils of wire, and is clearly a result of an electromotive-force setting up that current: thus it will be seen the two are very closely related.

As electricity and magnetic lines can hardly be thought of as matter, the definition of force given in § 1 would seem to require some alteration; but it is the one that is generally accepted.

* 3. Mass and Weight. The *mass* of a body is the quantity of matter in it: the *weight* of a body is due to the force of gravity acting upon this matter. The

[1] This term is not altogether a well defined one, but is helpful to the student.

larger a body, *i.e.*, the greater the quantity of matter in it, the more it will weigh, so that apparently, weight is the same thing as mass; but this is not so. As we said before, weight is due to the force of gravity acting on a body. Gravity is a force tending to pull bodies towards the centre of the Earth. Now this force diminishes as we get further away from the surface of the Earth, above or below; so that the force of gravity acting on a lump of lead, for instance, would be greater at the sea level than at the bottom of a mine, or up in a balloon; or in other words, it would weigh more in the first case than in the second. But the *mass* of the lump of lead would not alter, there would be just the same quantity of lead in it in each case. The Earth is not a perfect sphere, the distance from its centre to the surface being greater at the equator than at the poles: consequently, the force of gravity, and therefore the *weight* of a body, is slightly less at the equator than at the poles.

This difference in the weight of bodies at different parts of the Earth; or the difference between the weight as measured in a balloon at a considerable height, and at the Earth's surface; is too small to be readily appreciable, yet a difference does exist. This difference would not be detected at all if the body were weighed in an ordinary balance, however delicate; for the simple reason that just as the pull of gravity on the body in one scale-pan increased or diminished, its pull upon the "weights" in the other scale-pan would increase or diminish in exactly the same proportion; so

that balance would be obtained by the same "weights" at any part of the Earth.

By means of a very delicate spring-balance (Fig. 21), the difference in the pull of gravity on a body at different localities could be detected.

Though mass and weight are not the same thing, yet we can measure the mass of a body very conveniently by its weight. Thus, a body weighing 16 grammes has twice the mass or quantity of matter in it as a body weighing 8 grammes, at the same place (§ 6).

* 4. Units. Whenever we measure anything, such as the mass of a body, or its length, or a duration of time, we express the result according to the number of units.

Thus we say a ton of iron, a yard of wire, a second of time. In these cases, the ton, the yard, and the second are various *units*, of *mass*, *length*, and *time* respectively.

In ordinary every-day life we measure *mass* (or weight) in ozs., lbs., cwts., or tons, etc.; *length* in inches, feet, yards, miles, etc.; and *time* in seconds, minutes, hours, etc. These measures are not good, however, because of the use of different names to measure the same kind of thing; and also because of the trouble in reducing a value from a higher unit to a lower, or *vice versâ*. For instance, to reduce a ton step by step to ozs., we should have to multiply by 20, 4, 28, and 16: or to reduce a mile step by step to inches, it would be necessary to multiply by 8, 40, 5½,

3, and 12. To express, say 30 lbs. as a fraction of a cwt., or 100 yds. as a fraction of a mile, would take time, and necessitate the use of pencil and paper.

In the metric or decimal system, derived from the French, there is only one name to remember in connection with each set of measures, and the multiples and sub-multiples of a unit increase or diminish by 10, so that all calculations are easily and quickly made; the translation of a value to a higher or lower denomination being merely a matter of moving the decimal point to the right or left.

* 5. DECIMAL PREFIXES TO UNITS. The following are the metric or decimal prefixes to units: they may be used with any units, and they increase or diminish the values as follows:—

Meg or Mega	=	one million times	1,000,000
Myria	=	ten thousand times	10,000
Kilo	=	one thousand times	1,000
Hekto	=	one hundred times	100
Deka	=	ten times	10
	unit.		1·
Deci	=	one-tenth	0·1
Centi	=	one-hundredth	0·01
Milli	=	one-thousandth	0·001
Micro	=	one-millionth	0·000001

Thus:—

Megohm	=	1 million ohms.	(§ 23.)
Myria-volt	=	10,000 volts.	(§ 30.)
Kilogramme	=	1000 grammes.	(§ 6.)
Milli-ampere	=	·001 ampere.	(§ 27.)
Microfarad	=	·000001 farad.	(§ 40.)
Centimetre	=	·01 metre.	(§ 6.)

6. Metric Measures.

Length.

					Inches.	*Feet.*	*Yards.*	*Miles.*
Kilo-metre	=	1000 metres	=		39370·	3280·899	1093·633	·621
Hekto-metre	=	100 metres	=		3937·	328·089	109·363	·062
Deka-metre	=	10 metres	=		393·7	32·808	10·936	·006
Metre	=		=		39·37	3·280	1·093	·000
Deci-metre	=	·1 metre	=		3·937	·328	·109	·000
Centi-metre	=	·01 metre	=		·3937	·032	·010	·000
Milli-metre	=	·001 metre	=		·03937	·003	·001	·000

Mass.

					Grains.	*Lbs. (Avoir.)*	*Cwt.*	*Tons.*
Kilo-gramme	=	1000 grammes	=		15432·	2·204	·019	·0009
Hekto-gramme	=	100 grammes	=		1543·2	·220	·001	·0000
Deka-gramme	=	10 grammes	=		154·32	·022	·000	·0000
Gramme	=		=		15·432	·002	·000	·0000
Deci-gramme	=	·1 gramme	=		1·5432	·000	·000	·0000
Centi-gramme	=	·01 gramme	=		·15432	·000	·000	·0000
Milli-gramme	=	·001 gramme	=		·015432	·000	·000	·0000

Volume.

				Cubic centimetres.	*Cubic inches.*	*Cubic feet.*	*Pints.*	*Gallons.*
Kilo-litre	=	1000 litres (cubic metre)	=	1,000,000·	61027·051	35·316	1760·768	220·096
Hekto-litre	=	100 litres	=	100,000·	6102·705	3·531	176·076	22·009
Deka-litre	=	10 litres	=	10,000·	610·270	·353	17·607	2·200
Litre	=	[A cube, each edge of which = 1 decimetre]	=	1,000·	61·027	·035	1·760	·220
Deci-litre	=	·1 litre	=	100·	6·102	·003	·176	·022
Centi-litre	=	·01 litre	=	10·	·610	·000	·017	·002
Milli-litre	=	·001 litre	=	1·	·061	·000	·001	·000

From the first table it will be seen that practically a metre = 3 ft. 3 in. and $\frac{3}{8}$ of an inch, or approximately 40 ins. The centimetre is a very little over $\frac{3}{8}''$, or more correctly $\cdot 4''$, and the millimetre between $\frac{1}{32}''$ and $\frac{1}{16}''$. The inch is about equal to 2·5 centimetres, or 25 millimetres. 1 yd. = ·9144 metres.

7. THE C.G.S. OR ABSOLUTE SYSTEM OF UNITS. The C.G.S. (centimetre-gramme-second) or absolute system of units is founded upon the *fundamental units*—centimetre (length), gramme (mass), and second (time). It is called an ***absolute system*** as the units therein depend only on the three standards of length, mass, and time; which are presumed to be obtainable anywhere with exactitude; the term *C.G.S. system* is more frequently employed, however. The C.G.S. system being decimal, has great advantages over the *F.P.S.* (*foot-pound-second*) *system*, which is the basis of the ordinary British units of mechanical measurements. Another advantage is that the units are directly related; thus C.G.S. unit volume (1 c.c. of water at its greatest density) = unit mass, *i.e.*, 1 gramme. All the other units of the C.G.S. system, being based upon the above-mentioned three fundamental units, are called ***derived units***.

C.G.S. FUNDAMENTAL UNITS.

LENGTH. The *centimetre* (abbreviated *cm.*).
MASS. The *gramme* (abbreviated *gm.* or *grm.*).
TIME. The *second* (abbreviated *sec.* or ″.)

C.G.S. DERIVED MECHANICAL UNITS.

AREA. The *square centimetre* (abbreviated *sq. cm.*)
VOLUME. The *cubic centimetre* (abbreviated c.c.).
(One cubic centimetre = 1 milli-litre.) (§ 6).

VELOCITY. A body has unit velocity when it moves through unit distance (or length) in unit time. Thus, unit velocity is a velocity of one centimetre per second.

FORCE. The unit of force is that force which, acting on unit mass for unit time, gives it unit final velocity: or in other words, it is that force which, acting on a mass of 1 gramme for 1 second, gives it a final velocity of 1 centimetre per second. This unit is called the *dyne.*

The British unit of force is called the *poundal;* and is that force which, acting on a mass of 1 lb. for 1 sec., imparts to it a velocity of 1 ft. per sec. The force of gravity acting on a mass of 1 lb. for 1 sec., imparts to it a final velocity of 32·2 ft. per sec. in Great Britain. 1 lb. therefore gravitates with a force of 32·2 poundals.

The force which gravity exerts on a mass of one gramme (in London) is 981 dynes: so that $\frac{1}{981}$ gramme gravitates with a force of one dyne. Roughly one may say that the weight of 1 milligramme represents a force of 1 dyne. 1 lb. gravitates with a force of 444,981 dynes in London.

WORK. The unit of work is the work done in moving a body through unit distance against unit force: *i.e.*, the work done in moving a body through a distance of 1 cm. against a force of 1 dyne. Or it may be otherwise expressed as the work done in overcoming unit force through unit distance. The unit of work is called the *erg* (§ 8).

There are a great number of C.G.S. electrical units, but we shall only mention those which are of importance to the elementary student, as the need arises.

* 8. WORK. *Work is done when a force overcomes a resistance.* But force exerted does not always overcome the resistance opposed to it, and therefore does not always do work. When a railway truck is pushed along a line, work is done: but a man might exert all the force of which he were capable without doing any work, if he tried to move a very heavily-laden railway

truck, or to push down a brick wall. If a weight is lifted, work is done; the work being directly proportional to the weight, and to the distance through which it is moved. Thus, 6 ft.-lbs. of work are done in raising a mass of 1 lb. to a height of 6 feet, or a mass of 2 lbs. to a height of 3 feet. The resistance which is overcome in this case is that offered by the opposing force of gravity. Work, of course, does not always consist in lifting weights: for instance, work is done when an engine draws a train, or when an electric motor drives machinery; but the work may still be expressed in ft.-lbs. In the F.P.S. system, work is measured in *ft.-lbs.*: in the C.G.S. system it is measured in *ergs* or *kilogrammetres.*[1] 1 erg is the work done in pushing a body through a distance of 1 centimetre against an opposing force of 1 dyne. Or what is the same thing, it is the work done when a force of 1 dyne applied to a body moves it a distance of 1 centimetre. If in either case the distance through which the body had been moved had been 10 centimetres, then 10 ergs of work would have been done.

We saw in the last paragraph that a milligramme gravitates with approximately a force of 1 dyne; therefore we may say roughly that 1 milligramme raised to a height of 1 cm. represents 1 erg of work. The erg is obviously a very small amount of work, so that engineers use a unit called the kilogrammetre, which represents the work done in raising a weight of 1 kilogramme through a distance of 1 metre. If one

[1] *Kilogrammetre* is a shortened form of kilogramme-metre.

gramme gravitates with a force of 981 dynes (§ 7), a kilogramme will gravitate with a force of 981,000 dynes. From this, and the definition of the erg (§ 7) it follows that:—

$$1 \text{ kilogrammetre} = 98{,}100{,}000 \text{ ergs.}$$
$$= 98{\cdot}1 \text{ megergs.}$$

If a man merely supports a weight without moving it, from an engineering point of view he cannot be said to do work, for by definition:—

$$\text{work} = \text{force} \times \text{displacement.}$$

* 9. POWER. *Power is the rate of doing work*, and has nothing to do with the actual amount of work done. A boy would take longer to carry say a thousand bricks up a ladder on to some scaffolding than would a man. Yet when all the bricks were carried up they would represent the same amount of work done, though the boy might take twice or three times as long to do it as the man. This, of course, is leaving out of the question the work done by the man and the boy in lifting their own bodies against the force of gravity. The *power* or *rate-of-working* of the man would be greater than that of the boy. Consider another example. One engine might take 3 hours to draw a certain train from one place to another, while another might be able to take the same train between the same places in 1 hour. The latter engine would clearly be three times more powerful than the former, because it could do the same amount of work in one-third of the time taken by the first engine. When the train was drawn to its destination, it would

represent the same amount of work done, no matter whether it had travelled at the rate of a mile a minute or a mile an hour. This, of course, is leaving friction and air resistance out of account.

Power is estimated according to the amount of work done in a given time. In the F.P.S. system of ordinary mechanical measurements :—

33,000 ft.-lbs. of work done per minute = 1 H.P. (horse-power).

or :— 1 H.P. = 33,000 ft.-lbs. per min.
= 550 ft.-lbs. per sec.

* 10. Various kinds of Work. Work may be done in various ways,—*mechanically*, *chemically*, *thermally*, *magnetically*, or *electrically :* and it may be reckoned in *ft.-lbs.*, *kilogrammetres*, *ergs*, or *joules ;* yet it is still work. Similarly, power or "rate of doing work" may be reckoned in *H.P.* or in *watts.* Mechanical work is generally expressed in ft.-lbs., and mechanical power in H.P. (horse-power).

* 11. Electrical Work and Power. Electrical work (§§ 33, 34) is generally measured in *joules*, and electrical power in *watts.*

1 joule = 10,000,000 ergs.

1 watt = electrical work done at the rate of 1 joule or 10 million ergs (10 megergs) per second.

1 watt = $\frac{1}{746}$th H.P. (English).[1]

∴ 1 H.P. = 746 watts. = 1 E.H.P. (electrical horse-power).

[1] The French H.P. (force de cheval) = 736 watts, = 75 kilogrammetres per sec. = ·9863 H.P. (English).

The joule and the watt will be more fully considered later on (§§ 33, 34, 35).

12. EQUIVALENTS OF WORK AND POWER.

WORK OR ENERGY. 1 ft.-lb. = 13,560,000 ergs.
= ·138 kilogrammetres.
= 1·356 joules.

1 kilogrammetre = 9·81 joules.
= 7·233 ft.-lbs.
= 98·1 megergs.

1 joule = ·7373 ft.-lbs.
= ·102 kilogrammetres.
= 10,000,000 ergs.

1 erg. = ·00000007 ft.-lbs.
= ·00000001 joules.
= ·00000001 kilogrammetres.

POWER. 1 H.P. or 1 E.H.P. = 33,000 ft.-lbs. per min.
= 550 ft.-lbs. per sec.
= 746 joules per sec.
= 7,460 million ergs per sec.
= 76 kilogrammetres per sec.
= 746 watts.

1 watt = ·7373 ft.-lbs. per sec.
= 10,000,000 ergs per sec.
= 1 joule per sec.
= ·102 kilogrammetres per sec.
= $\frac{1}{746}$ or ·00134 H.P.

1000 watts (1 kilowatt) is the *commercial unit of electrical power* (§§ 28 and 29).

* 13. ENERGY. Energy is the capacity for doing work. Energy is expended when work is done. Energy and work are consequently measured in the same units.

* 14. DIFFERENCE BETWEEN ENERGY, FORCE, WORK, AND POWER. It is important that the student should clearly understand the difference in the meaning of the above terms. *Energy* is the capacity for doing work. *Force* is one of the factors of work, and has to be exerted or overcome through a distance, to do work; the work being reckoned as the product of the force and the distance through which it has been applied or overcome. *Work* is done when energy is expended, or, what is almost the same thing, when a force overcomes a resistance. *Power* is the rate of working, or the rate of expenditure of energy.

* 15. MOMENTUM. *Momentum* may be defined as the *quantity of motion* in a moving body. The momentum of a body is proportional to its mass multiplied by its velocity. To stop a moving body requires the application of force (§ 1). A rotating fly-wheel with a thick iron rim would require greater force to stop it than if its rim were made of wood: its momentum is greater in the first case. Momentum represents energy stored up in a moving body; thus a body with momentum is able to do work.

If a lump of lead and a lump of wood of equal size were let fall from the top of a tower into soft earth, the lead would bury itself to a greater depth than the wood, on account of its greater mass, *i.e.*, because of its greater momentum; both having the same velocity. Similarly, a leaden bullet fired from a gun would crash through a greater thickness of wood than a wooden bullet fired under similar conditions, and of the same size.

CHAPTER I.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. What is force?

*2. Does force necessarily produce motion?

*3. Mention various kinds of force.

*4. Explain concisely the difference between mass and weight.

5. Say why the weight of a body varies at different altitudes, and at various parts of the Earth.

*6. What are the advantages of a decimal system of measures?

7. Give the relation between the pound and the gramme, the foot and the metre, the pint and the cubic centimetre.

*8. Write out the decimal prefixes to units, showing how much they increase or decrease the value of the unit.

9. What is the difference between the C.G.S. and F.P.S. systems of units? Mention the advantages of the former.

10. Define the C.G.S. units of area, volume, velocity, force, work, and energy.

11. Show how and why a weight may be expressed as a force.

*12. Explain, with examples, the difference between work and power.

*13. Give the units of work and power.

*14. What are the electrical units of work and power?

15. Give, in full, the equivalents of work and power.

*16. *Define:* — mass, energy, power, weight, work, and momentum.

17. Give the values for the English and French horse-power in watts, and in ft.-lbs. per min.

*18. Define "work" and "power." How many foot-pounds of work will be done in twenty minutes by a motor working at 4 H.P.? [Prel., 1894.]

19. What are foot-pound, poundal, dyne, and kilogrammetre? And how are they related? [Ord., 1895.]

*20. Why can a leaden bullet be fired further than a piece of wood of same shape and size? [Prel., 1895.]

*21. If a man supports a weight of 10 pounds for 17 minutes, does he do any work? If so, how much? [Prel. 1895.]

22. Explain numerically the relations between the dyne, the erg, the joule, the kilogramme, the British horse-power, and the metric (French) horse-power. [Ord. 1894.]

*23. Why is energy expended in bending or coiling a spring? [Prel. 1896.]

CHAPTER II.

The figures refer to the numbered paragraphs.

* 16. Electricity. Though, like heat and light, the nature of electricity cannot be explained by comparison with anything else; it is, for simplicity, treated as a sort of fluid. It is frequently spoken of either as being "at rest" in the form of a *charge* on a body, or as flowing through a body in a *current*. When electricity is at rest on a body, we speak of the body as being "charged with electricity," or as having a "charge of electricity" upon it. When electricity flows through a body, we speak of it as a "current

of electricity." The student must bear in mind that these are merely expressions of convenience, which enable us easily to explain observed effects; and that no electrician thinks that there is anything tangible in either a "charge" or a "current" of electricity.

* 17. PRESSURE, RESISTANCE, CONDUCTORS, AND INSULATORS. Whether electricity will or will not "flow through" a substance at a measurable rate, depends both upon the *pressure* of the electricity, and the *resistance* which the substance opposes to its "flow." Lightning is electricity at high pressure, and under such high pressure it is enabled to flow through almost anything, even miles of air. The pressure at which electricity is used in practical work is very much less than that of a lightning flash; and with such low-pressure electricity there are some substances which offer such great resistance to its "flow," as practically to allow none to pass through them. These substances are called *non-conductors* or *insulators*, to distinguish them from *conductors*, or those substances which offer very little resistance to the flow of electricity. There is, however, no such thing as a perfect conductor or a perfect insulator. Every so-called conductor offers some resistance, and there is no insulator which will not allow *some* electricity to pass through it. There are some substances which are neither very good conductors or very good insulators, and which are therefore sometimes called semi-conductors. But whether we call any particular substance a conductor, a semi-conductor, or an insulator, must depend to a great

extent upon the pressure of electricity with which we have to deal.

Electrical pressure is measured in volts. Electrical engineers are able to produce any pressure from a fraction of a volt up to 50,000 volts, or even higher if necessary.

* 18. TABLE OF CONDUCTORS AND INSULATORS. With practical working pressures up to, say five or ten thousand volts, we may classify substances according to the following list, which is a table of bodies in their *order of conductance*, or power of conducting electricity. Those at the top of the list, the metals especially, offer very little resistance to the passage of electricity, and are therefore called conductors: as we descend the list, the bodies increase in resistance, becoming worse conductors and better insulators: those at the bottom offer extremely great resistance to the flow of electricity, and are therefore called insulators. Thus copper is a better conductor than iron, iron than mercury, mercury than carbon, carbon than slate, and so on.

As regards the metals, their order below may be taken to be practically correct, though with the alloys a slight variation in their composition makes a great difference in their conducting powers.

The arrangement of fair conductors, semi-conductors, and non-conductors must be taken to be only roughly correct; a slight variation in the quality of a substance would make a considerable difference in its place on the list.

Good conductors.

- Silver (annealed).
- Copper (annealed).
- Copper (hard drawn).
- Silver (hard drawn).
- Telegraphic silicium bronze.
- Silver copper alloy (equal parts).
- Gold (annealed).
- Gold (hard drawn).
- Aluminium.
- Telephonic silicium bronze.
- Zinc.
- Telephonic phosphor bronze.
- Brass (according to composition).
- Platinum.
- Iron.
- Gold silver alloy.
- Nickel.
- Tin.
- Lead.
- German silver.
- Platinum iridium.
- Platinum silver.
- Platinoid.
- Antimony.
- Manganin.
- Mercury.
- Bismuth.

Sometimes called conductors, sometimes semi-conductors.

- Charcoal and coke.
- Carbon.
- Plumbago.
- Dilute acids.
- Sea water.
- Saline solutions.
- Metallic ores.
- Living vegetable substances.
- Moist earth.

Semi-conductors.

- Water (ordinary).
- The body.
- Flame.
- Linen.
- Cotton.
- Dry woods.
  - Mahogany.
  - Pine.
  - Rosewood.
  - Lignum vitæ.
  - Walnut.
  - Teak.
- Marble.

Non-conductors or Insulators.	Slate. Oils. Porcelain. Dry leather. Dry paper. Wool. Silk. Sealing wax. Sulphur. Resin. Water (perfectly pure). Gutta-percha. India-rubber. Shellac. Ebonite. Mica. Jet. Amber. Paraffin wax. Glass (varies very much with quality). Dry air (according to pressure).

* 19. CONDUCTANCE AND RESISTANCE. *Conductance* is the power of conducting electricity: *resistance* is the opposition offered to its flow. Conductors have great conductance and little resistance, while insulators have little conductance and great resistance. Every conductor offers some resistance to the passage of electricity, and there is no insulator which has not some little conductance, *i.e.*, which does not allow some electricity to pass through it, though the quantity may be infinitesimal.

The comparative powers of conductance of bodies is called their *comparative conductance*: while, on the other hand, the comparative powers of resistance of bodies is called their *comparative resistance.* Thus we should say that the comparative conductance of copper is greater than that of iron, while the comparative conductance of iron is very much greater than that of

carbon. On the other hand, the comparative resistance of wood is enormously greater than that of iron or platinoid.

* 20. TABLES OF COMPARATIVE CONDUCTANCE AND COMPARATIVE RESISTANCE OF METALS AND ALLOYS. Silver being the best conductor has consequently the highest comparative conductance. In the following table the first column gives the comparative conductances, and the second the comparative resistances. The goodness of the conducting power of silver, *i.e.*, its comparative conductance, being denoted as 100, the values for all the other metals are proportionately less. On the other hand, if the comparative resistance of silver be taken as 1, the other metals will have proportionately higher values.

	(Approximate.) Comparative Conductance.	Comparative Resistance.
Silver (annealed)	100	1
Copper (annealed)	95·03	1·052
Copper (hard drawn)	93·08	1·075
Silver (hard drawn)	92·10	1·086
Gold (annealed)	73·10	1·368
Gold (hard drawn)	71·83	1·392
Aluminium (annealed)	51·65	1·936
Zinc	26·73	3·741
Brass (according to composition)	—	—
Platinum	16·61	6·022
Iron (pure)	15·48	6·463
Gold Silver	13·84	7·223
Nickel (annealed)	12·07	8·285
Tin (pressed)	11·39	8·779
Iron (telegraph wire)	9·94	10·05

	(Approximate.) Comparative Conductance.	Comparative Resistance
Lead (pressed)	7·66	13·05
German Silver	7·187	13·92
Platinum Iridium	6·898	14·50
Platinum Silver	6·168	16·21
Platinoid	4·591	21·78
Antimony	4·238	23·60
Manganin	3·141	31·84
Mercury	1·581	63·23
Bismuth	1·147	87·20
Carbon (for arc lamps)	·0373	2681·
,, (graphite)	·006721	14880·
Selenium	·000000002487	40,210 millions

Thus with wires of the same thickness, to get the same resistance as 100 yds. of silver wire, it would only be necessary to take 15·4 yds. of iron wire, 7·1 yds. of german silver wire, about 3·1 yds. of manganin wire, and so on. On the other hand, if equal lengths and thicknesses of say silver, copper, aluminium, iron, and platinoid wire were taken; and supposing the resistance of the silver wire to be 1ω, then the resistances of the other wires would be as follows: copper, $1·05\omega$; aluminium, $1·93\omega$; iron, $6·46\omega$; platinoid, $21·78\omega$.

21. Tables of Conductivity and Resistivity. The *resistivity* or *specific resistance* of a substance is the resistance between opposite faces of a centimetre cube (unit volume) of the substance, expressed in microhms The *conductivity* or *specific conductance* of a substance is the reciprocal or opposite of its *resistivity*, and therefore may be expressed in megamhos, for 1 microhm = 1 megamho (§ 22).

	Conductivity. (Specific Conductance.) At 0° Centigrade (Megamhos.)	Resistivity. (Specific Resistance.) (approx.). (Microhms.)
Silver (annealed)	·6702	1·492
Copper (annealed)	·6370	1·570
Copper (hard drawn)	·6238	1·603
Silver (hard drawn)	·6172	1·620
Gold (annealed)	·4900	2·041
Gold (hard drawn)	·4815	2·077
Aluminium (annealed)	·3461	2·889
Zinc (pressed)	·1792	5·581
Platinum	·1113	8·982
Iron (pure)	·1037	9·638
Gold Silver (Au. 67, Ag. 33)	·0927	10·78
Nickel (annealed)	·0809	12·36
Tin (pressed)	·0763	13·10
Iron (telegraph wire)	·0666	15·000
Lead (pressed)	·0513	19·47
German Silver (Cu. 60, Zn. 26, Ni. 14) (hard or annealed)	·0481	20·76
Platinum Iridium (Pt. 90, Ir. 10)	·0462	21·63
Platinum Silver (Pt. 67, Ag. 33)	·0413	24·19
Platinoid (Cu. 59, Zn. 25·5, Ni. 14, W. 1·5)	·0307	32·5
Antimony	·0248	35·21
Manganin (Cu. 84, Ni. 12, Mn. 4)	·0210	47·5
Mercury	·0106	94·34
Bismuth (pressed)	·00768	130·1
Carbon (for arc lamps)	·00025	(about) 4,000
„ (graphite)	·000045	(average) 22,200
Selenium	·0000000000166	60,000 millions

Cu. = Cuprum	= Copper.	Ag. = Argentum	= Silver.
Zn. = Zincum	= Zinc.	Ir.	= Iridium.
Ni.	= Nickel.	W. = Wolfram	= Tungsten.
Pt.	= Platinum.	Au = Aurum	= Gold.

N.B.—The composition of alloys varies considerably.

* 22. Unit of Conductance. The *mho* is the unit of conductance. A mho is the reverse or reciprocal of an ohm or unit of resistance (§ 23). For instance :—

$$
\begin{aligned}
10 \text{ ohms} &= \tfrac{1}{10} \text{ or } 0{\cdot}1 \text{ mho.,}\\
2 \text{ ohms} &= \tfrac{1}{2} \text{ or } 0{\cdot}5 \text{ mho.}\\
1 \text{ ohm} &= 1 \text{ mho.}\\
\tfrac{1}{2} \text{ or } 0{\cdot}5 \text{ ohm} &= 2 \text{ mhos.}\\
\tfrac{1}{10} \text{ or } 0{\cdot}1 \text{ ohm} &= 10 \text{ mhos.}\\
1 \text{ microhm} &= 1 \text{ megamho.}
\end{aligned}
$$

and so on.

* 23. Unit of Resistance. The ohm is the unit of resistance, for which the symbol ω (omega) is used. Thus 10 ohms $= 10\ \omega$.

1 million ohms $=$ 1 megohm $= 1\ \Omega$ (capital omega). ·000,001 ω or 1 millionth of an ohm $=$ 1 microhm.

A conductor has one ohm resistance when a pressure or potential difference (§ 30) of one volt causes a current of one ampere (§ 27) to flow through it. It is convenient to remember that a copper wire 10 feet long and 10 mils[1] diameter has about 1 ω resistance.

24. Resistance. The resistance of a wire depends on four things :—

(*a*) On its material.
(*b*) On its thickness or sectional area.
(*c*) On its length.
(*d*) On its temperature.

The resistance of a wire of any given material, at any given temperature, depends on its length and on

[1] 1 mil $=$ ·001″. 1 circular mil $=$ area of circle of 1 mil dia.

its sectional area; being directly proportional to the former, and inversely proportional to the latter. Or,—

$$R \propto \frac{L}{A} \qquad \text{(I)}$$

where *R* is the resistance, *L* the length, and *A* the area of cross-section of the wire.[1]

With a given thickness, the greater the length the greater must be the resistance of the wire. With a given length, the greater the cross-section the less will be the resistance.

In the case of ordinary wires, whose cross-section is circular; the area of a circle or the cross-sectional area of a circular wire of radius *r* or diameter *d* is:—

$$\text{area} = \pi r^2 = \frac{\pi}{4} d^2 \qquad \text{(II.)}$$

π (pi) being the ratio of the circumference of any circle to its diameter; thus in any circle

$$\frac{\text{circumference}}{\text{diameter}} = 3{\cdot}1416 = \pi \qquad \text{(III.)}$$

π being a constant quantity in (II.), it follows that the areas of circular wires are proportional to the squares of their diameters. In (I.), substituting d^2 for *A*, we get:—

$$R \propto \frac{L}{d^2} \qquad \text{(IV).}$$

If the length (*L*) of a wire be expressed in centimetres, its cross-section (*A*) in square centimetres, and its

[1] The sign $\propto$ means *is proportional to.*

specific resistance or resistivity (ρ)[1] in ohms, then its resistance (R) in ohms will be :—

$$R = \frac{L}{A} \rho \qquad \text{(V.)}.$$

In the resistivity table (§ 21) the values are given in microhms, so they must be divided by 1,000,000 to give ρ in ohms.

25. CALCULATIONS OF RESISTANCE OF WIRES.

Examples. (a) *The resistance of a conductor is proportional to its length.* (i.) Thus if 20 yds. of a certain gauge of wire have a resistance of 1 ω, the resistance of a mile of the same wire will be $1760 \div 20 = 88\,\omega$.

(b) *The resistance of a conductor is inversely proportional to its cross-sectional area.* (ii.) A wire of a certain material and length, having a cross-section of ·008 sq. cm., will offer twice the resistance of a wire having a cross-section of ·016 sq. cm. and similar in length and material.

(c) *The cross-section of circular wires is proportional to the squares of their diameters.* (iii.) Thus, if two wires of same length and material have diameters respectively of 2 millimetres and 4 millimetres, their cross-sections will not be as 2 : 4, but as 4 : 16. That is, one will have four times the area of the other; and consequently, other things being equal, one-fourth the resistance.

(d) *The resistance of a conductor of given sectional area and length is proportional to the resistivity of its material.* If we took wires of different materials, but of the same thickness and length; the different resistances could be approximately got at from the resistivity table in § 21, presuming we knew the resistance of one of the wires. (iv.) Thus, supposing we had wires of equal thickness and length, of silver, copper, iron (pure), and german silver; and presuming that the resistance of the silver

---

[1] ρ = Greek letter *rho*, used for resistivity values.

wire was 5 ω; then the resistance of the other wires would be respectively:—copper 5·2 ω, iron 32·3 ω, german silver 69 ω:—

For instance, in the case of the silver and iron wires:—

resis. silver : resis. iron :: resistivity silver : resistivity iron.[1]

or, 5 : x :: 1·492 : 9·638

$$i.e.,\ x=\frac{9{\cdot}638\times 5}{1{\cdot}492}=32{\cdot}3\ \omega$$

and so on with the rest.

(e) *With a given resistance and cross-section, the length of a*

---

[1] The student is supposed to be familiar with the working of decimals and simple equations. Decimal fractions should always be used in preference to vulgar fractions. We cannot be expected to enter into the explanation of simple arithmetical and algebraic workings in this book; but when it is necessary to use any mathematical expression that the ordinary beginner is likely to stumble over, it will be explained.

(i.) $a : b :: c : d.$

This is another way of stating that *a bears the same ratio or proportion to b as c does to d.* Or, as we say shortly, *a* is to *b* as *c* is to *d*. For instance:—

(ii.) 2 : 4 :: 4 : 8

and (iii.) 9 : 3 :: 18 : 6,

i.e. (ii.) 2 is half 4, and 4 is half 8,

and (iii.) 9 is 3 times 3, and 18 is 3 times 6.

In such a proportion, the two inner quantities multiplied together exactly equal the two outer quantities multiplied together. For example, in—

(i.) $b\times c=a\times d.$

(ii.) $4\times 4=8\times 2.$

i.e. 16=16.

(iii.) $3\times 18=9\times 6.$

i.e. 54=54.

As will be seen above (§ 25*d* etc.), we use this method when we have two related quantities and a third quantity; and wish to find a fourth quantity which will bear the same relation to

conductor will be proportional to its conductivity, and inversely proportional to its resistivity. (v.) If we had a yard of mercury wire (such as a glass tube filled with mercury); to get the same resistance with wires of say german silver, iron (pure), and copper, of same sectional area as the mercury in the tube; we should have to take about 4·5 yds. of german silver, 9·7 yds. of iron (pure), and 60 yds. of copper.

For instance, in the case of the mercury and the copper:—

length mercury	:	length copper	::	resis^{ty}. copper	:	resis^{ty}. mercury
i.e., 1	:	x	::	1·57	:	94·34
or, length mercury	:	length copper	::	conduc^{ty}. mercury	:	conduc^{ty}. copper
i.e., 1	:	x	::	·0106	:	·6370

(f) *To find the resistance of a wire, given its material, length, and sectional area.* (vi.) What is the resistance of a platinoid wire 6 yds. long, and having a sectional area of ·0052 sq. cm.?

$$\text{Spec. res. of platinoid } (\rho) = 32{\cdot}5 \text{ microhms}$$
$$= {\cdot}0000325 \text{ ohms.}$$
$$6 \text{ yds.} = 6 \times 91{\cdot}44 \text{ cm. (§ 6).}$$
$$\text{R (in ohms.)} = \frac{L\rho}{A} \text{ (Formula V. § 24.)}$$
$$= \frac{548{\cdot}64 \times {\cdot}0000325}{{\cdot}0052}$$
$$= \frac{{\cdot}01783}{{\cdot}0052} = 3{\cdot}43\ \omega.$$

(g) *The resistances of wires of same material and length will be inversely proportional to their weights.* For clearly, with a

---

the third as the second does to the first. Thus, supposing we wish to find a number x which will bear the same ratio or proportion to 27 as 3 bears to 12, we should set it out as follows:—

$$3 : 12 :: x : 27.$$
$$12 \times x = 27 \times 3.$$
$$\text{(By simple algebra) } x = \frac{27 \times 3}{12} = \frac{81}{12} = 6{\cdot}75.$$

That is, 3 being a quarter of 12, 6·75 is a quarter of 27.

given length, the cross-section, and therefore the conductance of a wire, will be proportional to the amount of metal in it, *i.e.*, to its weight. Therefore its resistance will be inversely proportional to its weight. This presumes that the wire is of uniform thickness throughout its length.

(vii.) Two iron wires of same length and quality of iron weigh respectively 1·5 kilogrammes and 20 kilogrammes. The resistance of the first length is 7 ω; what will be the resistance (x) of the other length?

$$7\,\omega : x :: 20 : 1{\cdot}5$$
$$x = \frac{1{\cdot}5 \times 7}{20} = \frac{10{\cdot}5}{20} = {\cdot}525\,\omega.$$

26. EFFECT OF HEAT ON THE RESISTANCE OF MATERIALS. Most metals increase in resistance on heating, regaining their original resistance on reaching their former temperature. This increase of resistance with temperature occurs to a greater extent with pure metals than with alloys.[1]

Carbon decreases in resistance, a fact which has to be borne in mind in working out calculations on glow lamps.

Liquids which are capable of electrolysis (Chap. XV.) lessen in resistance when heated. Others (mercury and other molten metals) which conduct, but are not split up or electrolysed, increase in resistance just as solid metals do.

The insulating powers (*i.e.* the resistance) of india-

[1] There is one notable exception to the general rule. Manganin (an alloy of copper, manganese, and nickel [p. 24]) rises in resistance slightly up to 40° centigrade, and falls in resistance at higher temperatures; but for most purposes its variability of resistance with temperature may be neglected.

rubber, gutta-percha, glass, ebonite, and other good insulators, decrease enormously with a rise of temperature.

* 27. Quantity and Current. The "rate" at which electricity flows through conductors is called *current*, and is measured in *amperes*.

Just as we can measure out a certain quantity of water, say a gallon, so is it possible to measure out electricity in a given quantity. The unit of electrical quantity is called the *coulomb*. A coulomb of electricity has nothing whatever to do with the pressure of electricity in volts, or the current (rate of flow of electricity) in amperes; any more than gallons of water have anything to do with pressure or head of water (due to the height of the reservoir), or the rate of flow of water through a pipe. But just as we say that water is flowing through a pipe at the rate of so many gallons per minute, so we speak of electricity as flowing through a wire at the rate of so many coulombs per second. Just as the rate of flow of water depends upon the pressure or head of water, and on the bore and length of the pipe; in like manner the rate of flow of electricity along a wire depends upon the electrical pressure or electromotive force at our disposal, and on the resistance of the wire.

When electricity flows through a wire at the rate of one coulomb per second, we say that it is flowing at the rate of one ampere, or that we have a current of one ampere.

A rate of flow of :—

2 coulombs per sec.	=	2 amperes.
6 coulombs per sec.	=	6 amperes.
30 coulombs per min.	=	·5 ampere.

---

1 milliampere	=	·001 ampere.
1 kilo-ampere	=	1000 amperes.

and so on.

If a steady current is flowing, we can always find out the quantity of electricity that has passed by, *i.e.*, the number of coulombs, by multiplying the current (in amperes) into the time of its flow (in seconds).

Thus :—

1 ampere for 30 seconds	=	30 coulombs.
1 ampere for 1 minute	=	60 coulombs.
10 amperes for 1 hour	=	$60 \times 60 \times 10$.
	=	36,000 coulombs.

28. The Board of Trade or Commercial Unit of Electrical Supply.

The *Board of Trade unit* (*B.O.T.*),[1] or *commercial unit* of electrical supply (often called *supply unit*), is equal to 1000 watt-hours; or what is the same thing, 1000 volt-ampere-hours (§ 29). That is to say, the consumer has received 1 B.O.T. when the constant rate of electrical working in watts (§ 33), multiplied by the number

[1] Many people use *B.T.U.* to signify Board of Trade Unit, but these letters more rightly stand for British Thermal Unit (§ 36).

of hours during which such electrical work has been done, is equivalent to 1000: or when the number of amperes of constant current, multiplied by the pressure or voltage, and by the hours during which such current has passed, equals 1000: or when the voltage, the current, and the time (in hours), multiplied together = 1000.

The watts rate of working, or the number of amperes flowing through any electrical installation, is not constant; for lights, motors, etc., are turned on and off at various times. Therefore it is more convenient to take into account the actual quantity of electricity supplied, and the constant pressure at which it is supplied; then:—

1 B.O.T. = 3,600,000 coulomb-volts.

i.e.,	3,600	coulombs	at	1000	volts	pressure.
or	36,000	,,	,,	100	,,	,,
or	360,00	,,	,,	10	,,	,,

It is necessary to take into account the pressure at which the electricity is supplied, as well as the electricity itself. Electricity costs nothing—it is everywhere. But electricity is not manifest, and therefore has no power to do work, until a difference of electrical pressure is set up. The electricity supply companies do not generate electricity, for that is impossible; what they do do by means of their large engines and dynamos, is to create and keep up a difference of electrical pressure.

Electricity without pressure has no commercial value,

for it is unable to do work. This then is the reason why pressure has to be taken into account in electrical supply. As an analogy, take the case of the water companies; they do not manufacture water, but they do create a difference of water level or water pressure, and therefore enable the water to do work in flowing from a high to a low level. If you have to work a water motor or turbine, a tank containing any number of gallons of water you like, but situate at a low level, say in the basement of the premises, would be of no use whatever. You must not only have water, but "head" or pressure of water as well. Just so with electricity.

29. EQUIVALENTS OF THE BOARD OF TRADE UNIT.

1 B.O.T. = 1000 volt-ampere-hours.
= 1000 watt-hours (for 1 watt = volt × ampere). (§ 33.)
= 1 kilowatt-hour.
= 3,600,000 coulomb-volts.
= 3,600,000 joules (for one joule = coulomb × volt). (§ 34.)
= 1·34 HP working for 1 hour.

For instance, the supply in each of the following cases is equal to 1 B.O.T. unit.

(*a*) A current or 10 amperes for 1 hour at a pressure of 100 volts.

(*b*) A current of 40 amperes for ½ hour at a pressure of 50 volts.

(*c*) A current of 20 amperes for 5 hours at a pressure of 10 volts.

(*d*) A supply of 36,000 coulombs at a pressure of 100 volts.

(*e*) A supply of 7,200 coulombs at a pressure of 500 volts.

(*f*) A supply of 20,000 coulombs at a pressure of 180 volts.

* 30. THE CIRCUIT. The circuit is the conducting path through which the electricity flows. Every circuit may be divided into three parts:—

(*a*) The source of electrical pressure (dynamo or battery).

(*b*) The apparatus to be worked (lamp, motor, heater, etc.).

(*c*) The wires or leads connecting the apparatus with the source.

In every electrical circuit we have also:—

(i.) E.M.F. (electromotive force), voltage, pressure, or P.D. (potential difference), tending to drive electricity round the circuit, measured in volts.[1]

(ii.) The rate at which electricity flows round the circuit, *i.e.*, current; measdred in amperes.

(iii.) The resistance of the circuit; measured in ohms.

* 31. OHM'S LAW. Ohm's law gives us the connection between the pressure, the resistance, and the resulting current in a circuit; and enables any one of these quantities to be determined if the other two are known. Whatever units be used, it has been found that the

[1] For difference between E.M.F. and P.D., see the Author's *Electric Wiring, Fittings, Switches, and Lamps.*

current in a circuit is directly proportional to the pressure or electromotive force, and inversely proportional to the resistance. Thus, if e stands for E.M.F., c for current, and r for resistance—

$$r=\frac{e}{c} \quad \text{whence } c=\frac{e}{r} \quad \text{and } e=cr.$$

This is known as Ohm's law, and is of great importance in electrical work, but in this simple form is only true for steady direct (or continuous) currents.

Ohm's law is true for any part as well as for the whole of a circuit. Thus, if we consider any portion of a circuit, and know the resistance (r) of that part, and the potential difference (P.D.) between its ends, the current (c) flowing through will be :—

$$c=\frac{\text{P.D.}}{r} \quad (\S\ 47.)$$

From the above, the truth of the following statements will be obvious :—

(*a*) With a given electromotive force or P.D., if the resistance be doubled the current will be halved; if the resistance be halved, the current will be doubled.

(*b*) When the current is to be kept constant, if the resistance is increased, the E.M.F. or P.D. must be increased in the same proportion, and *vice versâ*.

(*c*) With a given resistance, if the E.M.F. or P.D. is increased or lessened, the current will be increased or lessened. In other words, the current will vary exactly as the E.M.F. or P.D. varies.

Ohm's law is true whatever units be used; thus let—

E = E.M.F., P.D., or pressure in VOLTS.

R = resistance in OHMS (ω).

C = current in AMPERES.[1]

Then:—

$$R = \frac{E}{C} \quad \text{or } C = \frac{E}{R} \quad \text{or } E = C \times R;$$

or

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes.}} \quad \text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$
$$\text{and Volts} = \text{Amperes} \times \text{Ohms.}$$

A useful American method of getting either of these three equations is as follows:— write down the formula $\frac{E}{CR}$, put your finger over the quantity required, and it is equal to what remains.

* 32. Examples in Ohm's Law. (*a*) In a circuit there is a dynamo with an E.M.F. of 120 volts, and the *total* resistance of the circuit (including dynamo, lamps, and leads,) is 12 ω. What is the current?

Answer:—10 Amperes.

for $$\frac{120}{12} = 10.$$

(*b*) A dynamo has a constant P.D. at its terminals of 55 volts, and the lamp circuit has a resistance of 3 ω. What is the current?

Answer:—18·33 Amperes.

for $$\frac{55}{3} = 18{\cdot}33.$$

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[1] The term *ampère* is derived from the name of a French electrician, André Marie Ampère. It is now customary to omit the accent, as *ampere*, but it is a difficult habit to get into.

(*c*) If the E.M.F. in a circuit is 90 volts, and electricity is flowing round at the rate of 45 amperes, what is the total resistance of the circuit?

Answer :—2 ω.

for $\frac{90}{45}=2.$

(*d*) If a secondary battery with an E.M.F. of 60 volts can send a current of 35 amperes round a circuit, what is the total resistance of that circuit?

Answer :—1·714 ω.

for $\frac{60}{35}=1{\cdot}714.$

(*e*) If in a circuit of 3 ω resistance there is a current of 61 amperes, what is the E.M.F. in the circuit?

Answer :—183 Volts.

for $61 \times 3=183.$

(*f*) A battery with an internal resistance of ·43 ω, sends a current of 11·7 amperes round a circuit having a resistance of 1·5 ω. What is the E.M.F. of the battery?

Answer :—22·58 Volts.

for $11{\cdot}7 \times ({\cdot}43+1{\cdot}5)=11{\cdot}7 \times 1{\cdot}93=22{\cdot}58.$

* 33. Electrical Power and Work. *Work is done when a force overcomes a resistance* (§ 8). When a current flows round a circuit, electrical work is done; for the current is the result of E.M.F. or electrical pressure overcoming the resistance of the circuit. *Power* is the rate at which work is done. *Power* × *time* during which it is exerted represents the actual amount of *work* done.

To send electricity through a given resistance at a given rate, we have to apply a certain electrical pressure. The faster electricity is forced round the circuit

(*i.e.*, the greater the current), and the greater the resistance through which it is forced, the greater will be the power exerted. To send 1 ampere through 1 ω requires 1 volt, but to send 1 ampere through 10 ω requires 10 volts (*vide* Ohm's law, § 31). The pressure necessary to send a given current round a circuit is thus a measure of the resistance of the circuit; and if we multiply the pressure by the current, the product will represent the power exerted:—

power = pressure × current.

power exerted in whole circuit = E.M.F. (or total pressure) × current.

power exerted in any part of a circuit = P.D. between the ends of that part × current.

In any case, power = volts × amperes.

The unit of electrical power is the *watt*, and is that power exerted when a current of one ampere flows under a pressure of 1 volt: the watt is thus occasionally called the volt-ampere. The symbol Pw. is sometimes used to signify electrical power. Thus:—

watts (Pw.) = volts × amperes.

Expressed in symbols:—

$$\text{Pw.} = \text{E (or P.D.)} \times \text{C}.$$

$$\text{But E (or P.D.)} = \text{C} \times \text{R (by Ohm's Law)}.$$

$$\therefore \text{(substituting) Pw.} = \text{C} \times \text{R} \times \text{C}.$$

$$= \text{C}^2\text{R}. \text{ (When circuit has no back E.M.F.)}$$

The watts rate of working in the whole or any part of a circuit may thus be estimated by multiplying together the E.M.F. (or P.D.) and the current, or the square of

the current and the resistance. Worked examples are given in the Writer's *Electric Wiring, Fittings, Switches, and Lamps.*

Power is sometimes called *activity*, and the watt the unit of activity. The *activity in a circuit* is the rate of doing work. From this the meaning of the expression, *activity of a current*, which is sometimes used, will be understood. It is not, however, quite correct to speak of the activity of a current, for the activity does not belong to the current any more than to the pressure; because, as we have seen, it depends upon both. It is therefore more correct to speak of the *activity in a circuit.*

* 34. Electrical Work and Power. The rate of doing work, multiplied by the time during which the work is done, will give the total amount of work done. In other words, power × time during which it is exerted will give the amount of work done, *i.e.* :—

$$\text{work} = \text{power} \times \text{time}.$$

Power, being the rate of doing work, is measured by the amount of work done in a given time; and is got by dividing the work done, by the time it takes to do it. Thus :—

$$\text{work} = \text{power} \times \text{time};$$

$$\text{and power} = \frac{\text{work}}{\text{time}}.$$

The unit of electrical work is called the *joule*, and is the amount of work done by one watt in one second, or by one ampere flowing for one second under a pressure of one volt, or by one coulomb flowing by

under a pressure of one volt. The joule is thus sometimes called the *watt-second*, the *volt-ampere-second*, or the *coulomb-volt*.

$$\text{work} = \text{power} \times \text{time}.$$
$$\textit{i.e.}, \text{ joules} = \text{watts} \times \text{seconds}.$$
$$\text{But watts} = \text{E C} = \text{C}^2\text{R} \ (\S\ 33).$$
$$\therefore \text{joules} = \text{E C } t = \text{C}^2\text{R}t$$
where t is the time in seconds.

The watt is sometimes defined as work done at the rate of 1 joule per second.

* 35. Heating Effect of the Current: Joule's Law. Heat is a form of energy, and to develop heat some other kind of energy must be expended, and work done. Heat developed in an electrical circuit denotes the expenditure of electrical energy, or the doing of electrical work. When a steady current flows round a metallic circuit, the whole of the work done by it goes to the development of heat. Heat generated means work done; consequently heat is a form of work, and may be measured in the same units as work.

The heat developed by a current in a conductor (§ 48) is proportioned to the resistance of the conductor, the square of the current strength, and the time of its flow.

It must be clear that, with a given current, the greater the resistance the greater will be the heat developed, and the longer the current flows the greater the heat developed. The difficult point to remember

is that the heat depends on the square of the current: that is to say, if the current is doubled, four times the amount of heat will be generated, and so on.

This difficulty vanishes, however, if it be remembered that heat is a form or manifestation of work done; and we know that work done in a circuit depends, among other things, on the square of the strength of the current (§ 34).

The heating effect of the current is sometimes called the *joule effect*, after James Prescott Joule, who discovered the law relating to it. Simply expressed, this is:—

$$H = c^2rt.$$

Where H is the heat developed, c the current, r the resistance of the conductor, and t the time of flow.

36. HEAT UNITS. Any unit of work is also a unit of heat, for heat is a form of work done. We may therefore measure heat work done in joules thus:—

$$\text{Heat (in joules)} = C^2Rt. \qquad (\S\ 34.)$$

C, R, and t being in amperes, ohms, and seconds respectively.

1 *British Thermal Unit* (*B.T.U.*) is the amount of heat required to raise one pound of water from 60° F. to 61° F. That is, it practically represents a pound weight of water raised one Fahrenheit degree in temperature.

1 *Calorie or Therm* (French unit) is the amount of heat required to raise one gramme of water (*i.e.* one c.c.) one degree centigrade in temperature. Strictly

speaking the water should be at its greatest density, *i.e.*, at 4°C.

Joule's equivalent, represented by J, is the amount of energy in ergs equivalent to the calorie, or to the B.T.U.

1 B.T.U. = 780 foot-pounds = 1,060 joules = 10,600,000,000 ergs (J). = 252 calories.

1 Calorie = ·00396 B.T.U. = 3·1 foot-pounds = (approx.) 4·2 joules = (approx.) 42,000,000 ergs (J).

The heat in calories evolved by a current of C amperes flowing under a pressure E volts through a circuit of R ohms during a time t seconds is :—

$$\text{Calories} = C^2 \times R \times t \times \cdot 24 \quad \text{or } E \times C \times t \times \cdot 24.$$

For we have seen above that 1 calorie = 4·2 joules, and multiplying by ·24 is the same as dividing by 4·2.

The *kilogramme-degree-centigrade* is a quantity of heat one thousand times the calorie, and is a unit used where large quantities are dealt with.

37. Capacity. In § 16 it was explained that when electricity is at rest on a body, it is spoken of as a *charge*. Every conductor (or conducting body) is said to have a certain *capacity* for electricity, though not exactly in the same sense as a jug has a certain capacity for water, as the capacity of a conductor depends upon its position and surroundings.

The capacity of a conductor is measured by the number of coulombs of electricity it will hold when its potential or pressure is raised by a given amount. Thus, if one conductor requires three coulombs of electricity to raise its potential to one volt, while another

requires only one coulomb to raise its potential to the same degree, the capacity of the former conductor is three times that of the latter.

38. THE CONDENSER. When two conducting plates are placed opposite each other, with a sheet of insulating material between them, the arrangement is termed a *condenser*. A condenser may be defined as an apparatus for "condensing" or "accumulating" a charge of electricity. This is effected by increasing

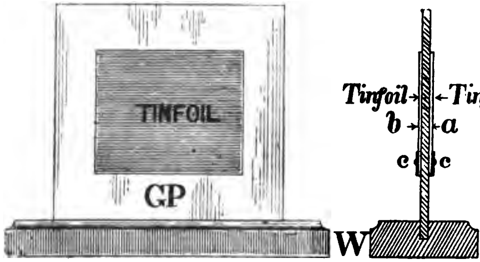

Fig. 1. Simple Condenser.

the capacity of a conductor by bringing it near another conductor. The action of a condenser depends upon influence (or electrostatic induction), and the attraction of unlike charges.[1] If an insulated conductor be far removed from other conductors,—hung up in the middle of an empty room, for instance,—a certain amount of electricity may be put into it, or abstracted from it,

[1] The theory of the condenser is more fully dealt with in the Author's *First Book of Electricity and Magnetism*, 2nd Edition (Whittaker).

before its potential is raised or lowered to a given degree. But if that conductor be near to (but not touching) another conductor, especially if the latter be earth-connected, or connected with the other end of the circuit, the capacity of the first conductor is increased; in other words, it will be possible to impart more electricity to it, or take more away from it, before its potential is raised or lowered to the same degree as before.

Fig. 1 represents a simple form of condenser. *GP* is a glass plate, say one foot square, with a sheet of tinfoil, about eight inches square, gummed on each side. The glass plate fits upright in a slot cut in a block of wood *W*, which serves as a stand. The tinfoil sheets are placed in the middle of each side of the glass plate, so that there is a strip of glass two inches wide all round. The glass, where not covered by tinfoil, should be varnished. The tinfoil sheets, marked *a* and *b* in the drawing, are called the *coatings* of the condenser. They should each have a little strip of tinfoil *cc*, soldered or fixed on, so as to form a kind of catch for the end of a wire, when it is desired to connect the condenser with anything.

The insulating material which separates the coatings of a condenser, and which may be glass, ebonite, gutta-percha, paraffined paper, air, or other good insulator, is called the *dielectric*.

Fig. 2 represents diagrammatically the construction of a condenser for practical work. Such a condenser may be made by interleaving sheets of tinfoil with stout note paper which has been previously dipped in

melted paraffin wax. This not only prevents the paper from getting damp, but fills up its pores and renders it altogether a better insulator. The thick lines *P* represent the paraffined paper or other suitable dielectric, such as mica; and the thin lines *T* represent the tinfoil sheets. Alternate sheets are connected together to form the two *coatings*, or *plates* of the condenser.

39. Action of a Condenser. The action of a condenser may be explained by saying that it accumulates electrical energy when one coating or set of plates is

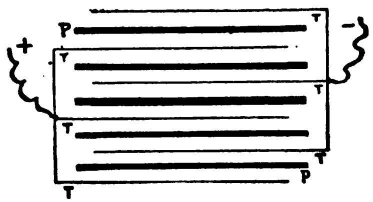

Fig. 2. Diagram of Condenser.

connected with one terminal of a source of electromotive force, and the other is connected with Earth, or with the other terminal of the source.

The following experiments with an influence machine will give an idea of the action of a condenser; but with such high pressure electricity, it is necessary to use one with a stout, thick dielectric, such as a simple condenser (Fig. 1), or a leyden jar.

Exp. 1. Disconnect the leyden jars of the influence machine. On working the latter, a continuous stream of thin sparks will pass between the terminals.

Exp. 2. Connect either of the coatings of a simple condenser (Fig. 1) to one of the terminals, the other coating being insulated. No appreciable difference will be noticed in the action of the machine.

Exp. 3. Connect one of the coatings to one terminal T of the machine, and the other coating to the other terminal T_1. (Fig. 3.) The machine when worked, instead of giving a continuous stream of sparks, will give sparks at intervals, but they will be much thicker than before.

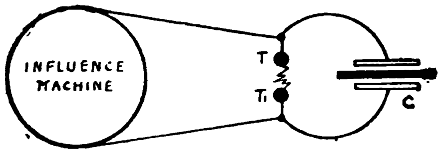

Fig. 3. Action of Condenser.

Apparently, electricity streams into the condenser c until it is fully charged; and then the condenser overflows, so to speak, and gives a very bright thick spark.

40. Unit of Capacity. The unit of capacity is called the *farad*. A condenser has a capacity of one farad when it requires a charge of one coulomb to raise the P.D. at its terminals to 1 volt. A condenser of such a capacity would be much too large for practical work; in fact, an average size of condenser used in testing is one having a capacity of 1 microfarad, *i.e.*, one-millionth part of a farad.

1 microfarad = 1 mfd. = ·000001 farad.

41. ENERGY IN A CONDENSER. When a condenser is charged by a steady pressure, the energy stored up by the condenser is half that taken up from the charging circuit, because the potential difference across the condenser plates begins with nothing, and ends with the P.D. of the ends of the circuit; its average value being thus half that of the charging pressure. The energy is therefore partly stored up in the condenser, and partly dissipated in the act of charging. The energy absorbed from the circuit in charging is obtained by multiplying the quantity (Q) and the charging pressure (V) together, giving joules, for joules = coulombs × volts (§ 34). If the capacity (K) and V be given, Q may easily be found, for:—

$$Q = KV.$$

Then $Q \times V \times \cdot 7373$ (*i.e.* joules × ·7373) = foot-pounds of work expended in charging the condenser (§ 12).

To find the energy in the condenser, *i.e.*, that which will appear on discharge, the formula—

$$K \times V^2 \div 2{\cdot}712 \quad \text{(foot-pounds)}$$

may be used. This would be found to give just half the value obtained by the above method for any case where a capacity is charged at a fixed pressure.

That is:— $\dfrac{K \times V^2}{2{\cdot}712} = \dfrac{Q \times V \times \cdot 7373}{2}$ = ft.-lbs. work done

by discharge. As, however, Q cannot be found without knowing K, it is more convenient to use the first

expression. Thus the energy of discharge of a condenser

$$= \frac{KV^2}{2 \cdot 712} \text{ ft.-lbs.} = \frac{KV^2}{2} \text{ joules (§ 12)},$$

K being the capacity of the condenser in farads, and V the charging pressure in volts.

42. USES OF CONDENSERS. Condensers are indispensable in telegraph work, and Mr. Swinburne has maintained that they may prove of use in alternate-current electric lighting. He has constructed tinfoil condensers with thick paper dielectric compressed between iron plates, and placed in a solid iron air-tight box filled with paraffin oil to maintain the insulation. The action of condensers with alternating currents, and the theory of their use in electric-light work, cannot be considered here.

CHAPTER II.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. What is the difference between an electric charge and a current of electricity?

*2. *Define:* conductor, insulator, resistance, conductance, pressure.

3. Explain the difference between conductance and conductivity.

*4. Arrange the following in their order of conductance: platinum, platinoid, copper, bismuth, and german silver.

*5. Arrange the following in their order of resistance: silver, ebonite, aluminium, guttapercha, iron, wood, and manganin.

6 How are the conductivity and resistivity of metals measured and expressed?

*7. On what does the resistance of a wire depend?

8. A copper conductor of a certain gauge has a resistance of 1·6 ω per 100 yds. Find the resistance of 320 yds. of the same conductor.

9. A certain length of copper wire has a cross section of ·003 sq. cm., and a resistance of 72 ω. What will be the resistance of a wire ·011 sq. cm. cross section, and of equal length?

10. What are the relative cross sections of two conducting cables, the diameters of which are respectively 700 mils. and 5 mm.?

11. A certain copper wire has a resistance of 2·3 ω. What will be the resistance of a manganin wire of similar length and gauge?

12. A certain length and gauge of platinoid wire has a resistance of 30 ω. How much longer must a copper wire (of the same gauge) be to give the same resistance?

13. What is the resistance of a copper wire ⅛th of a mile long, and ·006 sq. cm. cross section?

14. If you had two bundles of the same kind, quality, and gauge of wire, how could you tell approximately their relative resistances by weighing them?

*15. Say what you know about electrical pressure.

*16. Name the units of conductance, resistance, pressure, quantity, and current.

*17. Say exactly what you understand by a current of electricity.

18. What is the effect of heat, generally speaking, upon the resistance of conductors and insulators?

*19. Distinguish between quantity and current. How can the quantity of electricity which has passed through a conductor be ascertained?

20. Why has pressure as well as quantity to be taken into account in the supply of electricity?

21. What is the commercial unit of electrical supply?

22. Give six equivalents of the above unit, other than those mentioned in this book.

*23. Every circuit may be divided into three parts; what are they?

*24. What is Ohm's law?

*25. A dynamo which maintains a constant P.D. at its terminals of 105 volts, is connected with a circuit having a resistance of 5·7 ω. What is the current?

*26. A circuit containing a dynamo whose E.M.F. is 60 volts, has a current of 30 amperes flowing round it. What is the resistance of the circuit?

*27. What is the P.D. at the ends of a circuit having a resistance of 12 ω, and carrying a current of 17 ampères?[1]

28. How would you ascertain the power absorbed and work done in any given portion of an electric circuit?

29. Explain clearly what is meant by *activity in a circuit.*

30. Define the terms *watt, joule, coulomb, Board of Trade unit*, as applied in electric measurement. Distinguish between *work* and *power*. Is a *foot-pound* a unit of work or power? [Ord. 1890.]

31. State and explain Joule's law of the development of heat in a circuit.

*32. What are the watt, pound, horse-power, volt, ampere and ohm? Give any relations you can between them. [Prel. 1895.]

33. Define one watt, one kilowatt, and one horse-power. Also, if 1 ft. = 30.48 cm., and 1 lb. = 453·6 grammes, calculate the number of ergs equal to one foot-pound at a place where the acceleration of gravity is 981 cm. per second. Lastly, calculate the number of ergs per second equal to 1 h.p. [Ord. 1896.]

*34. Define an ampere, 10,000 volts, one megohm, a kilowatt, 40 Board of Trade units, and 100 h.p. [Prel. 1897.]

*35. Define a dyne, watt, horse-power, joule, Board of Trade unit. [Prel. 1898.]

36. Distinguish between the Board of Trade unit and the calorie.

37. Say what you know about *capacity.*

38. Explain the construction and action of a simple condenser.

39. *Define:* microfarad, condenser, capacity, dielectric, watt.

40. A condenser having a capacity of two microfarads is connected to two terminals maintained at 2,000 volts; how much work is taken from the terminals, and how much can be got out of the condenser again? [Ord. 1895.]

41. One of the Ferranti mains between Deptford and London has a capacity of 3 microfarads. What is the work stored in it, in ergs, if the inner and outer conductors are charged to a potential difference of 10,000 volts? [Ord. 1892.]

42. What do you know regarding the use of condensers?

*43. How does the resistance of the following substances vary with the temperature: carbon, copper, glass, guttapercha, iron, manganin, platinoid? [Prel. 1897.]

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[1] Numerous other examples of calculations based on Ohm's Law, etc., are given in the Author's *Electric Wiring, Fittings, Switches, and Lamps*, which is a supplement to this work.

CHAPTER III.

The figures refer to the numbered paragraphs.

* 43. ELECTRICITY. Whatever electricity may be, we assume for convenience that it is a something or other which can flow through a conductor when a difference of potential, or electrical pressure, or electrical level is set up between the ends of that conductor: or, in other words, when the conductor forms part of a circuit containing a source of E.M.F.

* 44. CURRENT. When electricity flows along a conductor, we speak of it as a current. There are two chief kinds of current.

(*a*) direct, or continuous;
and (*b*) alternating.

A direct or *continuous current* is one which flows round the circuit always in the same direction, while an *alternating* or *alternate current* is one which changes in direction many hundred times a minute. For the present we shall only consider direct currents, alternating currents being briefly dealt with in the author's "Alternating-Current Circuit," and in Chap. XI. Currents of electricity may be obtained either from dynamos or batteries, but these must not be looked upon as generators of electricity—that is impossible, but rather as arrangements for creating or setting up a difference of electrical pressure or level, thereby causing electricity to flow round the circuit.

* 45. Potential. The *potential* at any point in a circuit is the electrical pressure or level above or below that of the Earth, which is taken as zero: just as we measure heights or depths from the sea level, or temperatures with respect to that of melting ice. Electrical potential above that of the Earth is called *positive* (+); and below that of the Earth, *negative* (−). It is possible for two points in a circuit to be both either at a + or at a − potential, and yet there may be a difference of potential, or a potential difference between them. Whenever a *potential difference* (*P.D.*) is created, electricity is set in motion, and may be supposed to flow from the point at high potential to the point at low potential, when the points are connected by a conductor.

Everything may roughly be considered to be imbued or saturated with a something called electricity, but so long as there is no potential difference, no electrical

manifestation will take place. Every electrical circuit may be supposed to be charged with electricity at rest, and at the normal or zero potential. The introduction of a dynamo or battery sets up an electromotive force, and creates a potential difference between the ends of the circuit, and so sets the electricity in motion: consequently the dynamo or battery must not be looked upon as a device for supplying electricity to the circuit, but as a kind of electrical pump for pumping or setting into motion the electricity already existing there. The greater the electromotive or electro-pumping force, *i.e.*, the greater the P.D. set up between the ends of the circuit, the faster will the electricity flow round, and therefore the greater will be the current.

* 46. ACTION OF A DYNAMO OR BATTERY. A primary or secondary cell (or battery) may be looked upon as an electric pump, in which the electromotive or "electro-pumping" force is set up by the chemical action going on within the cell. A dynamo is also an electric pump, whose E.M.F. is due to the movement of conductors and magnetic lines-of-force across each other. A direct-current dynamo, like a battery, is a pump which works continuously in one direction. An alternator may be likened to a pump exerting its force first in one direction and then in the other, producing a rapid oscillation of electricity in the circuit, instead of a continuous flow in one direction. When a battery or direct-current dynamo is joined up in an incomplete circuit, it may be likened to a pump, *P* (Fig. 4) whose

inlet and outlet are connected round by a pipe in which is a stopcock, *S C*, the whole being watertight, and filled with water. If the stopcock be closed, working the pump will produce a difference of pressure on the two sides of the stopcock, the pressure being greater than the normal on the right-hand side, and less than the normal on the left-hand side; the difference of pressure (indicated in the figure by + and

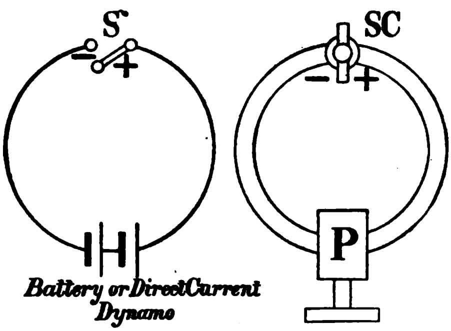


Fig. 4. Hydraulic analogue illustrating the Electric Circuit.

– signs) depending upon the "watermotive force" of the pump. If the stopcock be opened, there will be a continuous flow of water round the circuit, the rate of flow depending on the "watermotive force" of the pump, and on the internal diameter and shortness of the pipe circuit. When the battery (or dynamo) is on open circuit (Fig. 4), *i.e.*, when the switch *S* (which corresponds with *S C* in the right-hand figure,) is "off," and before the E.M.F. is allowed to act, we may consider

that the wires and battery (or dynamo conductors) are imbued with electricity evenly distributed. When the E.M.F. acts, the circuit still being open, there is a momentary passage of electricity through the battery (or dynamo), creating a potential difference between the two ends of the circuit; but as the E.M.F. of a battery or ordinary dynamo is small as compared with that of an influence machine, for instance, there will be practically no spark or other discharge across the air-gap at the switch. When, however, the latter is closed, there will be a continuous flow of electricity round the circuit, the rate of which (in amperes) will be directly proportional to the E.M.F. of the battery or dynamo (in volts), and inversely proportional to the resistance of the circuit (in ohms). Ohm's law, or the law of direct-current flow in the electric circuit, is comparable with the law of flow of water in the pipe circuit.

*47. FALL OF POTENTIAL. Dependent upon the E.M.F. of the dynamo or battery, and on the resistance of the whole circuit, there is a certain P.D. set up between the ends of the circuit where it is joined to the terminals of the dynamo or battery; this P.D. is measured in volts, and the potential is said to fall from the + end of the circuit to the − end. The total *fall of potential* in volts is equivalent to the P.D. between the ends of the circuit. Thus, if the P.D. is 100 volts, the potential falls from 100 volts at the + end of the circuit to zero at the − end.

If the circuit conductor is uniform in conductivity

and cross section, the fall of potential will be uniform. Fig. 5 illustrates this by an hydraulic analogy.

The water in the cistern *C*, which is kept at a constant level, has a certain definite head or pressure, in feet, for instance. It is allowed to discharge itself through the horizontal pipe *P* of uniform bore. If a number of vertical open tubes be fixed at equal distances along this discharge pipe, the water will rise in each tube to a certain height, depending on the

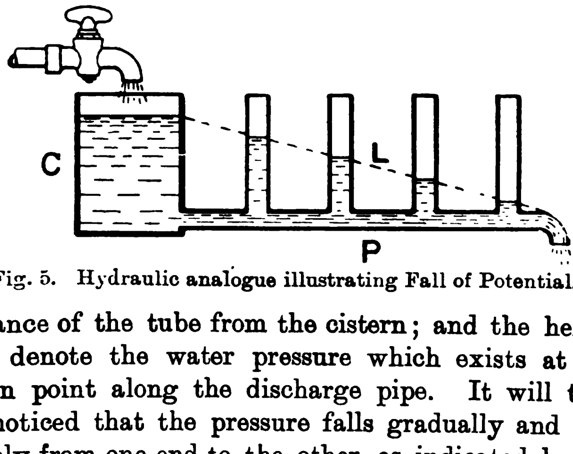


Fig. 5. Hydraulic analogue illustrating Fall of Potential.

distance of the tube from the cistern; and the height will denote the water pressure which exists at any given point along the discharge pipe. It will then be noticed that the pressure falls gradually and uniformly from one end to the other, as indicated by the dotted line *L*.

Compare Fig. 5 with Fig. 6, where *a c* is a wire of uniform conductance. *a* and *c* are connected respectively with the + and – terminals of a dynamo *D*, which maintains a P.D. of 100 volts between the ends of the wire *a c*. The potential therefore falls

uniformly (as indicated by the sloping dotted line) from 100 volts at *a* to zero at *c*. At a point *b*, midway along the wire, the potential would be 50 volts below *a*, and 50 volts above *c*.

On the other hand, suppose the circuit be made up of sections having different resistances for a given length. The fall of potential will not be uniform, being most sudden where the resistance is greatest,

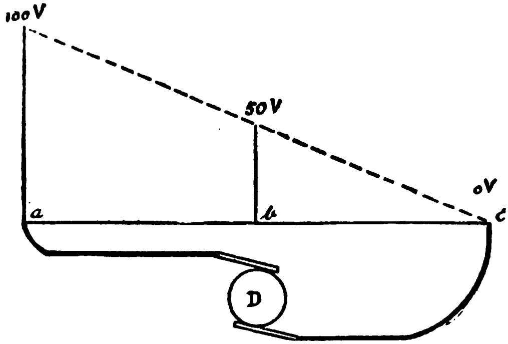


Fig. 6. Fall of Potential.

and more gradual where the resistance is least. This will be understood from the following figures, 7 and 8, which should be compared with Figs. 5 and 6. In Fig. 7 the discharge pipe *P* is not uniform, and the fall of pressure, as indicated by the height of the water in the vertical tubes, is greater in those sections which have the smaller bore.

In Fig. 8 there is a drop of, say 10 volts, between *a* and *b* and between *c* and *d*: but the sections *b c* and *d e* of the circuit, having greater resistance, cause a

drop of, say 40 volts, in each case. Therefore:—***with a given current, the fall of potential in any part of a circuit is proportional to the resistance of that part.***

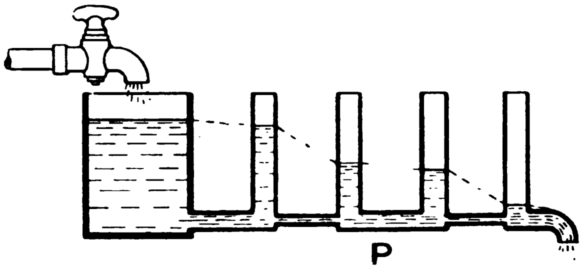


Fig. 7. Hydraulic analogue illustrating Fall of Potential.

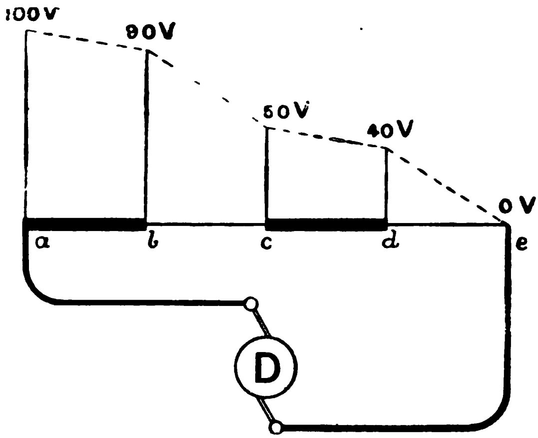


Fig. 8. Fall of Potential.

A correct understanding of fall of potential (or *drop in volts* as it is sometimes termed,) in a conductor, is of great importance in practice. Bearing in mind that

the *fall of potential*, or *drop of volts*, or *loss of volts* in a conductor forming part of a circuit, is the same as the P.D. between the ends of the conductor; the truth of the following statements, which embody the application of Ohm's law to part of the circuit, will be evident.

(*a*) Current in conductor =

$$\frac{\text{Drop in volts along conductor}}{\text{Resistance of conductor}}$$

(*b*) Resistance of conductor =

$$\frac{\text{Drop in volts along conductor}}{\text{Current in conductor}}$$

(*c*) Drop in volts in conductor = Resistance of conductor × Current in conductor.

Numerical examples are given in the Author's *Electric Wiring, Fittings, Switches, and Lamps.*

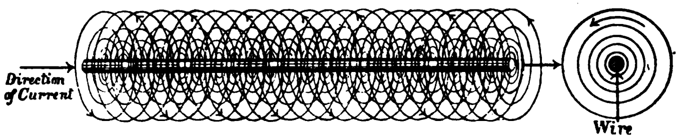


Fig. 9. Magnetic Field due to a Direct Current in a Straight Conductor.

* 48. Effects of a Current. The chief effects of a current are four in number:—

(*a*) *Magnetic.* A current flowing along a conductor sets up a magnetic field around the conductor. If the conductor be straight, the field will consist of concentric circular lines of force (Fig. 9). If the conductor be coiled up into a spiral, the field will be made up of lines running more or less

through the coil, and out at either end. (Fig. 17.)

(*b*) *Heating*, or *Luminous*. Whenever a current flows along a conductor, heat is developed in the conductor, the rate depending on its resistance and on the current. (§ 36). If the current is great, and the wire thin, sufficient heat will be developed to render the wire incandescent. This is the principle on which glow lamps are constructed.

If the two ends of a circuit having a P.D. of above 40 volts be brought together and then slightly separated, an intense light will play in the gap thus introduced in the circuit. This light is due to the formation of the *electric arc*, and the colour of the light emitted depends on the material composing the ends of the circuit between which the arc plays. This is the principle of the arc lamp.

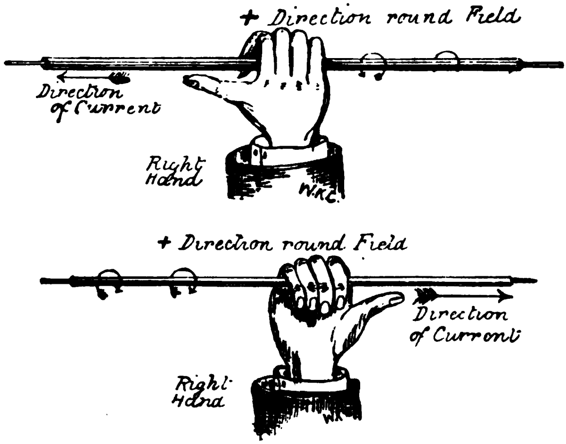
(*c*) *Chemical*. When electricity is passed through certain chemical solutions, it splits them up into their constituents. This action is known as electrolysis, *i.e.*, electric analysis (Chap. XV.).

(*d*) *Physiological*. The passage of currents through the body produces contraction of the muscles, etc.; and when a current is maintained under a high pressure, death generally ensues.

* 49. Magnetic Effect of the Current. Because of the magnetic field set up round a conductor carrying a current, a magnetic needle placed above or below

the conductor and parallel with it, will tend to turn at right angles with the conductor, and how far it succeeds in doing this will depend upon the strength of the current. If the current, and therefore the field, be strong, the conductor will pick up iron filings.

A *magnetic field* is any space filled with lines of



Figs. 10 and 11. Right-hand Rule for finding the + direction round the Magnetic Field of a Straight Conductor carrying a Direct Current.

magnetic force. These lines, when once set up by a steady direct current, do not move, but we suppose a certain "positive" and "negative" direction along them, just as we speak of the "up" or "down" directions along a road or railway. The *positive direction* along the lines of a magnetic field is the direction in which a free N. pole, if it were possible to get one,

would travel; viz., from the N. to the S. pole of a magnet or solenoid, through the air outside.

* 50. **Rules giving the relation between a Direct Current in a Conductor, and the Positive Direction round its Field.**

(*a*) **Right-hand rule for finding the positive direction round the magnetic field of a straight conductor carrying a direct current**[1] (Cullingford). (Figs. 10 and 11.) *Place the right hand across the conductor, with the palm facing*

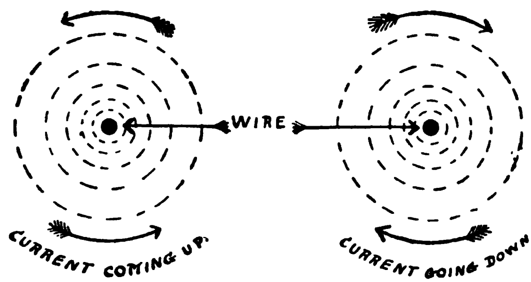


Fig. 12. Direction of the Magnetic Field round a Conductor.

the conductor, and the outstretched thumb pointing in the direction of the current: then the fingers curled round the wire will denote the positive direction along the conductor's circular lines of force.

[1] N.B.—In this and all following hand rules (excepting only the Rule in §63) the right hand is used. In all cases, for uniformity's sake: (i.) the thumb denotes the direction of the current; (ii.) the hand is placed with its palm facing the conductor; (iii.) the first, and sometimes also the other fingers denote the + direction along the field. [See paper by the Author in *Electrical Review*, Jan. 15th, 1892.]

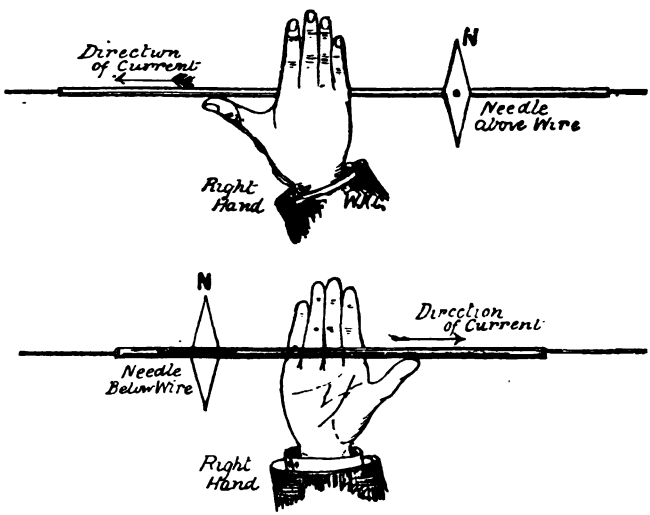
(*b*) Clockface rule. (Figs. 9 and 12.) *Looking at the end of the conductor, if the current is going from us, the positive direction round the field is the same as that in which the hands of a clock move (clockwise): if the current is coming to us, the positive direction round the field is opposite to that in which the hands of a clock move (counter clockwise).*

(*c*) Screw rule. *Associate the rotation and travel of a right-handed screw with, respectively, the + direction round the field, and the direction of the current, looking at the end of the conductor.* Thus, to drive the screw in it must be turned in a clockwise direction: the current goes in and the field is in a clockwise direction. To bring the screw out it must be turned in a counter clockwise direction: if the current is coming out, the field is in a counter clockwise direction. We look at the head of the screw and the end of the conductor.

* 51. Right-hand Rule for finding the Direction of Deflection of a Magnetic Needle by a Direct Current in a Conductor. (Maycock.) (Figs. 13 and 14.) *Place the right hand across the conductor, and on the same side of the conductor as the magnetic needle; with the palm facing the conductor, and the outstretched thumb pointing in the direction of the current: then the fingers will denote the direction in which the N. pole of the needle will turn.*

The converse of this rule, given in the next paragraph, is the more useful, as it enables us to tell the direction of the current, by observing the deflection of a magnetic needle held above or below the conductor.

* 52. Right-hand Rule for finding the Direction of a Direct Current in a Conductor. (Maycock.) (Figs. 13 and 14.) (1) *Move the conductor, if possible, into the magnetic meridian.* (2) *Hold a small compass needle above or below the conductor, and observe the direction in which the N. pole of the needle is deflected.* (3)



Figs. 13 and 14. Right-hand Rule for finding the direction of deflection of a Magnetic Needle by a Direct Current.

Place the right hand the same side of the conductor as the needle, with the palm facing the conductor, and the fingers pointing in the direction of deflection of the N. pole of the needle. Then the outstretched thumb will denote the direction of the current.

* 53. Magnets. A magnet is anything which has the power of attracting pieces of iron or steel apart from most other bodies. There are two principal kinds of magnet, *permanent* and *electro*. The former are made of hardened steel, and when once magnetised, retain their power. The latter are due to the magnetic effect of the current, described in § 49, and are generally

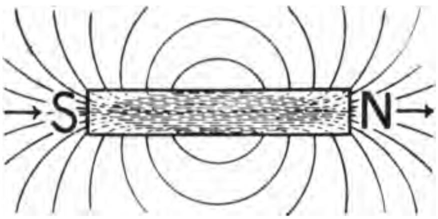


Fig. 15. Magnetic Field of a Bar Magnet.

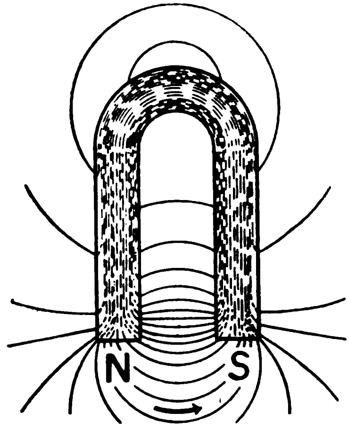


Fig. 16. Magnetic Field of a Horseshoe Magnet.

made by winding an insulated conductor around soft iron. When electricity flows through the conductor the iron becomes magnetic, but loses most if not all of its magnetism directly the current ceases. There need not necessarily be iron in an electro-magnet, but the addition of iron increases the magnetic effect. For instance, when a current flows through a conductor, that

conductor becomes an electro-magnet throughout its entire length, for it is able to pick up iron filings. (§ 49.)

* 54. Lines of Force. The power which any magnet possesses, of picking up pieces of iron, and of acting upon another magnet, depends upon the existence of *lines of magnetic force.* In the case of a permanent magnet, the majority of these lines pass through the air from the N. to the S. pole, and through the substance of the magnet itself from the S. to the N. pole; as shown in Figs. 15 and 16, where the arrows denote the

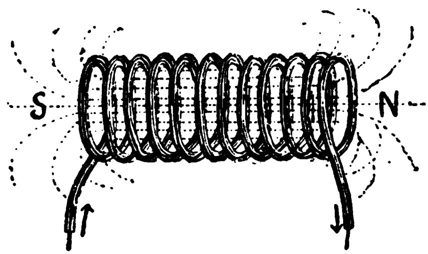


Fig. 17. Magnetic Field of a Solenoid.

+ direction along the field.[1] In the case of a straight current-carrying conductor, the lines of force arrange themselves in concentric circles about the conductor (Fig. 9). In the case of a helix or solenoid, the lines run more or less through the coil and out at each end (Fig. 17). If there be iron in the electro-magnet, such as an iron bar in a straight coil of wire, more of the lines pass from end to end of the coil, without leaking

[1] Fig. 16 is only fairly correct as regards the disposition of the field.

out at the sides, and the number of lines is very much increased (Fig. 18).

* 55. MOLECULAR THEORY OF MAGNETISM. According to this generally accepted theory, every molecule of iron or steel is a complete magnet having a N. and a S. pole. In the so-called unmagnetised condition of the metal, these magnetised molecules are so jumbled up as to complete their magnetic circuits through themselves: consequently no lines pass into the air, and

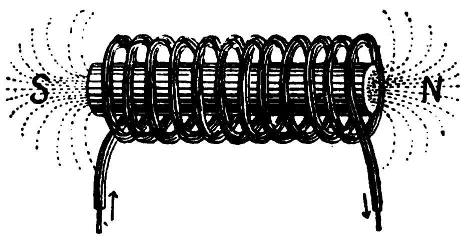


Fig. 18. Simple Bar Electro-Magnet.

there is no *free magnetism.* If lines of force, either from another magnet, or due to a current in a conductor, be caused to pass through a piece of iron or steel; all the little magnetised molecules, previously jumbled up, will set themselves, more or less, in straight rows along the lines which are passing amongst them, with their N. poles pointing in the + direction along the lines. The effect of this is to give us a free N. pole at one end of the piece of iron or steel, and a free S. pole at the other end. In this condition the iron or steel is said to be *polarised.* In the case of hardened steel, the molecules when once set in line remain so, hence the

permanent magnetisation. With soft iron, on the other hand, directly the inducing lines of force are removed, the molecules, which may be supposed to be very much less closely packed together than the molecules of hardened steel, tend to jumble themselves up again, and wholly or partially succeed in so doing, according to the softness and quality of the iron. Hence the fact of the temporary magnetisation of an electro-magnet.

In engineering work, without disputing the molecular theory, it is found more convenient to talk about good and bad *conductors of magnetic lines.* Thus air, and brass, and other non-magnetic bodies conduct magnetic lines rather poorly; while iron and steel have very great magnetic conductance. (Chap. VI.)

* 56. Straight-wire and Spiral Electro-magnets. It is possible to utilise and increase the magnetic effect of a straight current by the arrangement shown in Fig. 19, which may be termed a straight wire electro-magnet: *NS*, *NS*, *NS*, is a length of split iron tube, such as a piece of gas-pipe cut in half longitudinally, *NNN* being the N. pole, and *SSS* the S. pole: or as in Fig. 20, representing a spiral electro-magnet; *NS* being a spiral of iron wire enclosing the conductor. In each case the circular lines pass through the iron, polarise it, and give us free poles, as shown. In the latter case there would be some leakage of lines, and therefore polarity, at the beginning and end of each turn of the spiral. Such electro-magnets are of little practical use, for the effect obtained is very slight,

owing to the small number of lines due to the current which are utilised.

* 57. The Solenoid. The lines due to the current are concentrated by coiling up the wire, the lines altering their shape as shown in Fig. 17. Such an arrangement is termed a solenoid. A solenoid has N. and S. magnetic poles, and the result of introducing a bar of soft iron into the coil would be to very greatly

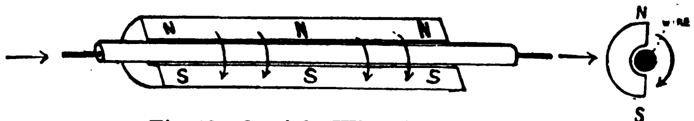


Fig. 19. Straight-Wire Electro-Magnet.

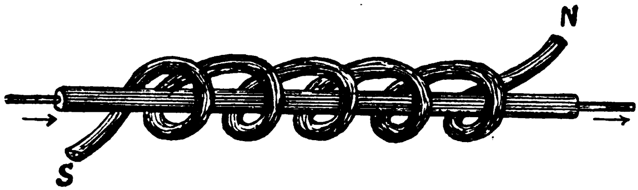


Fig. 20. Spiral Electro-Magnet.

increase the magnetic effect; for the lines due to the current pass through the iron, polarise it, and bring into action a number of lines of force due to the magnetised iron bar, in addition to those previously due to the current in the solenoid. Every line of force is separate and distinct from every other line of force, no matter how closely packed together they may be; and every line forms a complete curve which varies in shape, according to circumstances: consequently a line

of force has no end. This we can understand with regard to the circular lines due to a straight current; but in the case of a bar magnet, or solenoid, some of the lines appear to lose themselves in the air and end there. This is not the case, however; each individual line completes its curve, though we may not be able to follow it throughout its whole path.

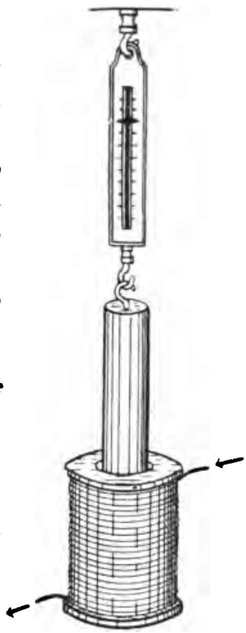


Fig. 21. Attractive Force of a Solenoid.

In Fig. 17, representing the magnetic field of a solenoid, it will be noticed that some of the lines do not pass through the whole length of the coil, but leak out at the sides and curve round to complete their circuits. This is due to the tendency of every line of force to shorten itself as much as possible. Because of this leaking away, there are more lines passing through the centre of a solenoid than out at either end. If a piece of iron be suspended over the mouth of a solenoid (Fig. 21), it will be forcibly drawn in to the centre of the coil, the tendency being for the piece of iron to travel to that part of the field where the lines are most densely packed together. On this account it is said that lines of force always tend to shorten themselves, and to follow as short a

path as possible. This action of the solenoid is made use of in various devices.

* 58. TYPES OF ELECTRO-MAGNET.[1]

(*a*) *Straight wire.* (§ 56; Fig. 19.)

(*b*) *Spiral.* (§ 56; Fig. 20.)

(*c*) *Bar.* (§ 54; Fig. 18.)

(*d*) *Horseshoe.* Fig. 22 shows three kinds of horseshoe electro-magnet. In the first and second, the iron core of the magnet is in one piece;

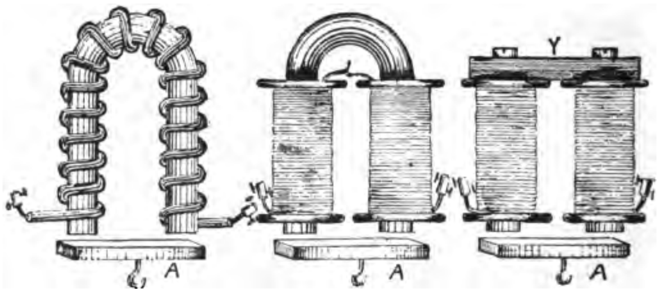


Fig. 22. Three kinds of Horseshoe Electro-Magnet.

while in the third, the two cores are screwed to a back piece of iron (*Y*) termed the yoke. *AAA* are the armatures.

(*e*) *Horseshoe with one coil on the yoke.* (Fig. 23.) In this type there is only one coil, which is fixed on the middle part of the core (or the yoke).

[1] For further information on this subject, the student is referred to Prof. Silvanus P. Thompson's standard treatise on *The Electro-magnet*.

(*f*) *Club-foot.* (Fig. 24.) One coil only is used also in this magnet, but it is placed on one of the legs of the magnet, instead of on the yoke, as in type (*e*). In neither of these cases (*e* and *f*) is a

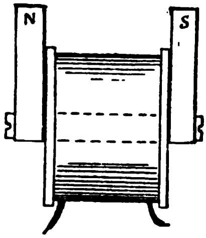


Fig. 23. Horseshoe Electro-Magnet with one Coil on Yoke.

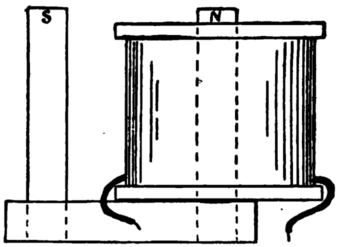


Fig. 24. Club-foot Electro-Magnet.

saving of wire effected, for to obtain a given number of lines of force with a given mass and form of iron core, and a similar current, the number of turns must be nearly the same in each case (§ 86).

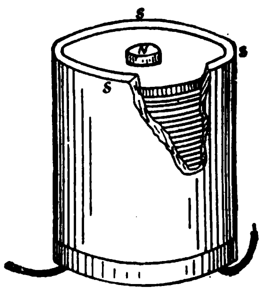


Fig. 25. Ironclad Electro-Magnet.

(*g*) *Ironclad.* (Fig. 25.) In this magnet, the coil on

which the wire is wound has the top cheek of brass or zinc, and the bottom one of iron. The core *N*, and the top edge of the iron cylinder *SSS*, which fits over the coil and core, form the two poles of the magnet, while the iron coil-cheek at the bottom forms the yoke. An appropriate armature for such a magnet would be a disk of soft iron. The ends of the coil pass through holes in the bottom cheek.

(*h*) *Annular ironclad.* (Fig. 26.) This magnet is

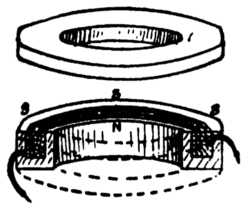


Fig. 26. Annular Ironclad Electro-Magnet.

somewhat similar in principle to the straight wire magnet shown in Fig. 19, except that it is circular in shape, and has a number of turns of wire. The inner face forms the N. pole and the outer face the S. pole, while the flat washer acts as armature. The figure shows the coil and core in section, the front half being cut away.

There are very many modifications of each of the above principal types, according to the circumstances under which the magnet is to be employed.

A form of electro-magnet which is largely used in

experimental work, consists of a ring of iron over-wound with insulated wire (Fig. 75). In this case the iron is magnetised, but the lines of force complete their path entirely in the iron, and there is no free magnetism. The term "electro-magnet" generally implies the presence of free poles, and the consequent use of air as a portion of the path of the lines of force. The free poles can then be used to attract iron armatures, etc.

* 59. Rules for determining the Polarity of a Solenoid, or of an Electro-magnet.

(*a*) Right-hand rule for finding the polarity of

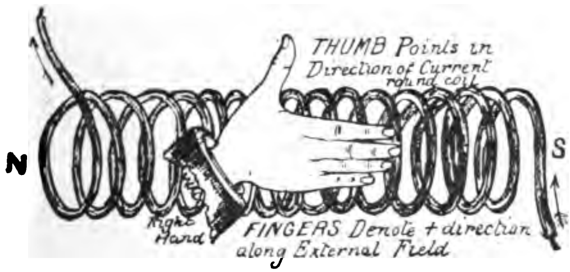


Fig. 27. Right-hand Rule for finding the Polarity of a Solenoid or Electro-Magnet.

a solenoid, or of an electro-magnet (Maycock) (Fig. 27). *Place the right hand lengthways on the solenoid, or on the coil of the electro-magnet, with the palm facing the solenoid or coil, and the outstretched thumb pointing in the direction of the current: then the fingers will point in the + direction along the external field, i.e., towards the S. pole.*

(*b*) Clockface rule (Fig. 28). *Looking at the end of the solenoid or of the coil of the electro-magnet, if the current is circulating in a clockwise direction, the pole facing the observer is S.: if the current be circulating in a counter clockwise direction, the pole is N.*

(*c*) Screw rule. To assist in remembering rule *b*. *Associate the rotation and travel of a right-handed*

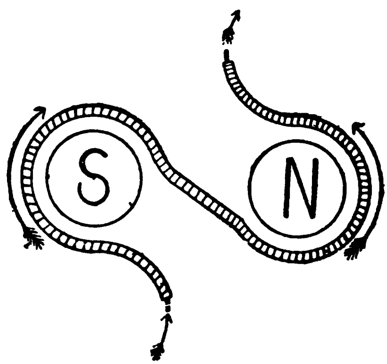


Fig. 28. Clockface Rule for determining the Polarity of a Solenoid or Electro-Magnet.

screw with, respectively, the circulation of the current, and the movement (attraction or repulsion) of an imaginary free N. pole held in front of the solenoid or magnet pole. The polarity of the latter is deduced from the movement (attraction or repulsion) of the little free pole.

For supposing the pole to be S., then the little test N. pole would be attracted towards it; if

it is desired to make the screw travel in the same direction, it must be turned in a clockwise direction. Therefore, we argue that the current round the pole is also in a clockwise direction. On the other hand, supposing the pole to be N., the little test N. pole would be repelled towards the observer. If the screw is to travel in the same direction, it must be unscrewed, *i.e.* turned in a counter clockwise direction. From this we infer that the current round a N. pole is in a counter clockwise direction. We look at the head of the screw, and the face of the pole.

59A. ALTERNATING CURRENT ELECTRO-MAGNETS. If an alternating current be sent round an electro-magnet with a solid iron core, the latter will become very hot, and therefore only comparatively slightly magnetised.

In Chapter XVI. it will be shown that when an alternating current flows round a circuit, a secondary alternating current is induced in a neighbouring circuit.

If an alternating current be sent round the coil of a solid core electro-magnet, the core may be looked upon as a neighbouring conductor, and secondary currents (or, as we would call them in this case, *eddy currents*,) will be continuously set up in the core, absorbing a good deal of energy, and at last heating the core so much that the insulation of the coils may be burnt away.

The cores, yoke, and armature of an electro-magnet intended for use with alternating currents, should be

made of the best and softest iron, and most carefully laminated (§ 164): each part being insulated from the other. This stops the circulation of eddy currents in, and consequent excessive heating of, the core; and the iron is thus rendered more susceptible to the rapid reversals of the magnetic field.[1]

An alternating current magnet with a solid core is less effective than the same with a laminated core, for three reasons:—(1) the waste of energy in heat; (2) the higher temperature (the susceptibility of iron to magnetisation decreases as the temperature increases, as proof of which it will be remembered that a magnet will not attract a red-hot piece of iron); (3) the demagnetising effect of the eddy currents.

Badly designed alternating current magnets, transformers, etc., "hum" when the current is passing. This may be supposed to be due to the continuous movement of the molecules of the iron core.

Electro-magnetic phenomena are more fully dealt with in Chapters IV. and VI.

CHAPTER III.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Distinguish between a direct and an alternating current.

*2. What do you understand by *potential* and *potential difference?*

[1] The heating of a solid core in the manner described has been suggested by Ferranti, Rankin Kennedy, and others as a form of *electric heater*. Most forms of electric heater derive their heat from current circulating in wires of high resistance.

*3. Show clearly by explanation (in your own words) and sketches what is meant by the *fall of potential* round a circuit.

*4. Under what circumstances is the fall of potential round a circuit uniform?

*5. How do you regard the action of a dynamo or battery when it sets up a current in a circuit?

*6. Enumerate the chief "effects" of an electric current, and name a practical application of each.

*7. *Define:* magnetic field, + direction along lines of force, electrolysis.

*8. Knowing the direction of the current in a conductor, how would you deduce therefrom the + direction of the field?

9. Draw a solenoid showing roughly the lines of force before and after the introduction of a soft iron core. [Ord. 1895.]

*10. In how many ways could you find out the direction of the current in a conductor?

*11. *Define:* magnet, permanent magnet, electro-magnet, lines of force.

*12. What is meant by the expressions "drop in volts," or "loss of volts"?

13. Explain in your own words the molecular theory of magnetism.

*14. Under what conditions is a bar of iron or steel said to have "free magnetism"?

*15. How could you magnetise iron by means of a current in a straight conductor?

*16. Give sketches of the magnetic fields due respectively to the current in (i.) a straight wire, (ii.) a solenoid, (iii.) a solenoid with an iron core, and (iv.) a semicircular solenoid.

*17. Explain the distribution of lines of force in a current-carrying solenoid, and say how and why the introduction of an iron core alters that distribution.

*18. How could you magnetise a steel corkscrew by means of the current in a straight wire?

19. Give a concise list, with sketches, of the principal types of electro-magnet. Draw some form not shown in this book.

*20. Explain the difference between bar and horseshoe electro-

magnets. Say which you think is the most convenient kind for any purpose, and why.

21. Give sketches of two kinds of ironclad electro-magnet, showing clearly the direction of the current, and of the field.

22. Mention a type of electro-magnetic apparatus in which there are magnetic lines of force, but no free poles.

23. Supposing you had to make two similarly shaped electro-magnets, one for use with direct currents, and the other for alternating currents: would you construct them the same way or not? Give reasons and sketches.

*24. Why does an electro-magnet pull so much less if you take out the iron core and replace it with a brass one? [Prel. 1895.]

25. Why would an alternate-current magnet with a solid core be less efficient than if it had a laminated one?

*26. An electro-magnet is required to work quickly, and to let go the armature instantly on the cessation of the current. How could this result be obtained? [Prel. 1901.]

*27. If two similar iron bars are put together inside a solenoid, what is the effect on them (1) when the bars are placed end to end; (2) when they lie side by side? [Prel. 1898.]

28. Calculate the size, resistance and weight of copper wire such that, if wound on a magnet core 7 in. by 3½ in., and having a potential difference of 25 volts maintained between the terminals, 5,000 ampere-turns will be produced. Length inside former is 8 in. [Ord. 1898.]

29. Calculate the size, resistance and weight of copper wire such that, if wound on a cylindrical iron core 6 ins. long, 3½ in. diameter, and having a P.D. of 50 volts between its terminals, 4,440 ampere-turns will be produced. The diameter of the completed coil is to be 7¾ in. A cubic foot of copper weighs 550 lbs. [Ord. 1900.]

CHAPTER IV.

The figures refer to the numbered paragraphs.

* 60. Induction of Currents. We have seen that when electricity flows through a straight conductor, circular lines of force are set up round the conductor. Also, when electricity flows round a solenoid or coil, lines of force are set up which pass through the coil.

The converse of these is true, for:—

(*a*) If we take a straight conductor forming part of a closed circuit, and bring it into an independent magnetic field, so that it cuts the lines of force, a momentary current will be induced in the conductor: and when it is withdrawn from the field, a second momentary current will be induced, in the opposite direction to the first induced current.

(*b*) If we take a coil forming part of a closed circuit, and poke lines of force from an independent source into it, so that they cut the conductor, a

momentary current will be induced: and when the lines are withdrawn, another momentary current will be induced, in the opposite direction to the first current.

Bearing these observations in mind, the following experiments on electro-magnetic induction will be clearly understood.

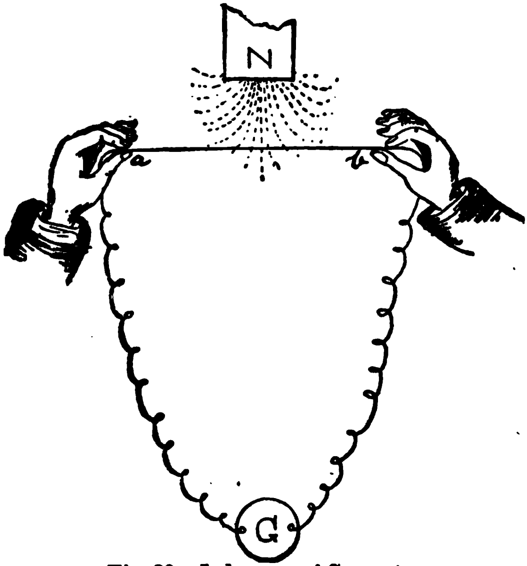


Fig. 29. Induction of Currents.

* 61. Experiments on Electro-magnetic Induction.

(*a*) *Required.*—A strong bar magnet, and a length of wire joined up with a sensitive mirror galvanometer *G* (§ 119), far enough away as to be out of reach of the direct influence of the magnet.

Experiment.—Fig. 29. If the conductor be passed up and down across the field of the magnet, momentary currents will be set up, as indicated by the movement of the spot of light on the scale. The induced current will be in one direction when the wire is moved down, and in the other when it is moved up. The direction of the induced currents will be reversed according as the N. or S. pole of the magnet is used.

As the magnetic field in front of the pole of a bar magnet is not generally so strong as that between the poles of a horseshoe magnet, the latter will give better results, especially if it be an electro-magnet.

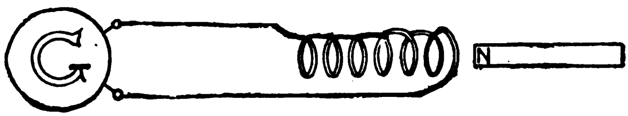


Fig. 30. Induction of Currents.

(*b*) *Required.*—A bar magnet, and a coil of many turns of wire (into which the magnet may be passed), joined up with a galvanometer *G* (Fig. 30).

Experiment.—The momentary induced current is in one direction when the magnet is brought up to the coil, and in the other direction when it is taken away. The approach of the N. pole of the magnet induces a current in the opposite direction to the current induced by the approach of the S. pole. Again, with either pole, the direction of the induced current depends upon

the end of the coil to which it is brought up. If the magnet be introduced right into the coil, a greatly increased effect is obtained.

The coil may be moved instead of the magnet, the latter being stationary. Bringing the coil up to the magnet has the same effect as bringing the magnet to the coil, and so on.

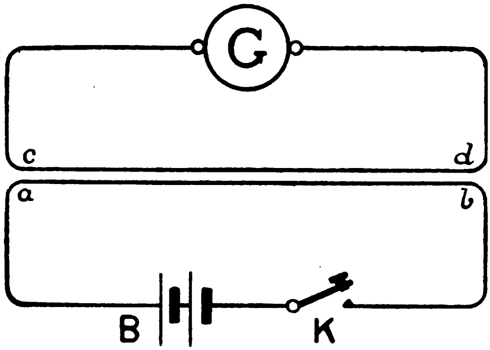


Fig. 31. Induction of Currents.

(*c*) In Fig. 31 two distinct circuits are represented, one containing a battery *B* and a key *K*, and the other a sensitive galvanometer *G*. The portions *a b* and *c d* of the circuits are for some 2 or 3 feet close together and parallel with each other, but not in metallic contact. If the key be depressed, the current in *a b* induces a momentary reverse current in *c d*. But when the current in *a b* is stopped, a momentary direct current is induced in *c d*. Keeping the circuit closed, the

same effect will be obtained if the wire *a b* is taken away from or brought up to *c d*; the currents induced being respectively direct and reverse. By the term *direct current*, as here used, is meant an induced current flowing in the same direction as the inducing current; while a *reverse current* is one flowing in the opposite direction to the inducing current.

(*d*) As in Exp. *b*., a greater effect was obtained by coiling the circuit up; so in the last experiment,

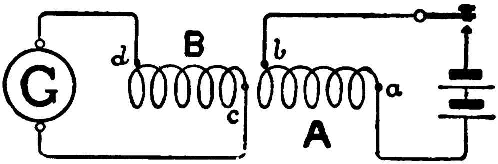


Fig. 32. Induction of Currents.

if the portions *a b* and *c d* of the two circuits are coiled up, as shown in Fig. 32, the induced currents will be much stronger. The starting of a current in coil *A*, or the approach of coil *A* (while carrying a current) will induce a reverse current in *B*. The interruption of the current in coil *A*, or the recession of *A* (while carrying a current) from *B*, will induce a direct current in *B*.

(*e*) As might be expected, the effects obtained in Exp. *d* are much increased if the coils are slipped one within the other, as shown in Fig.

33, and still more so if they are provided with a soft iron core common to both.

(*f*) While the coils are one within the other, and the key is kept down, no movement of the galvanometer will be detected. If now the iron core be first introduced into and then withdrawn from the coil, momentary reverse and direct currents will be indicated.

Bearing in mind that the strength of the induced

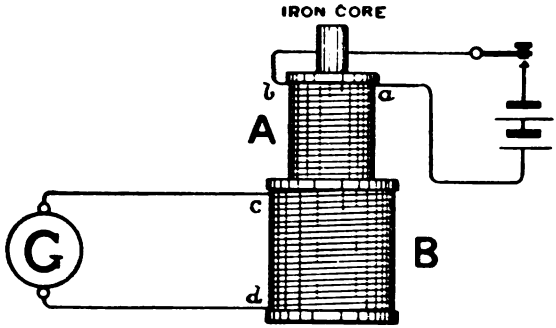


Fig. 33. Induction of Currents.

current depends upon the number of the inducing lines of force, and the number of turns of wire cut by the lines; the increased effects obtained by:—(i.) coiling the wire up; (ii.) using a current-carrying coil instead of a bar magnet; (iii.) placing one coil within the other; and (iv.) introducing the iron core, are easily explained.

62. Laws of Electro-magnetic Induction.

(*a*) Faraday's Law. *Let any conducting circuit be*

placed in a magnetic field: then if by a change in position or a change in the strength of the field, the number of lines passing through, or interlinked with the circuit is altered; an E.M.F. will be induced in the circuit, proportional to the rate at which the number of lines is altered.

(*b*) General Laws.

(i.) *A decrease in the number of lines of force which pass through a circuit induces a current round the circuit in the positive direction, (i.e., induces a "direct" current): while an increase in the number of lines of force which pass through the circuit induces a current in the negative direction, (i.e., induces a "reverse" current).*

(ii.) *The total induced electromotive force acting round a closed circuit, is proportional to the rate of increase or decrease in the number of lines of force which pass through the circuit.*

* 63. Left-hand Rule for finding the Direction of the E.M.F. induced in a Conductor which is moved across a Magnetic Field (Fig. 34.).—(Maycock.)

Place the left hand across the conductor with the palm facing the conductor, and the thumb, forefinger, and other fingers stretched out at right angles, as shown in the figure; the forefinger must point in the positive direction along the field, and the other fingers in the direction of motion: then the thumb will denote the direction of the induced current.

64. Comments on preceding Experiments.

It is more correct to speak of *induction of E.M.F.*

than of *induction of current*, for a current can only flow when the *secondary circuit*, i.e., the circuit in which the E.M.F. is induced, is closed. The term *induction of current* is very commonly used, however.

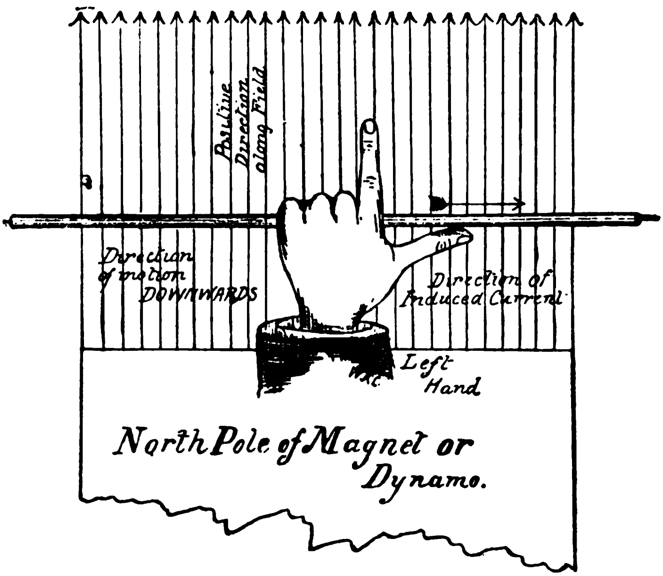


Fig. 34. Left-hand Rule for finding the direction of the E.M.F. induced in a Conductor which is moved across a Magnetic Field.

The student should apply the left-hand rule to show that:—

(*a*) The current is from *b* to *a* (Fig. 29) when the wire is moved down, or when (the wire being fixed) the pole is moved up.

(*b*) The current is from *a* to *b* (Fig. 29) when the wire is moved up, or when (the wire being fixed) the pole is moved down.

(*c*) The results mentioned in (*a*) and (*b*) are reversed by using the S. pole of the magnet.

The left-hand rule may also be applied to predict the direction of the induced currents in the experiments illustrated in Figs. 30, 31, 32 and 33. In Fig. 30, think of the tuft of lines proceeding from the N. pole of the magnet, and the direction in which they cut the first turn of the coil. In Fig. 31, imagine an end view of the wires *a b* and *c d*; figure to yourself the circular lines spreading out from *a b* and collapsing again, when the primary or inducing circuit is respectively made and broken, and think of the direction in which they cut the wire *c d*. In Fig. 32, the lines-of-force due to coil *A* are practically the same shape as if *A* were a bar magnet; and having found the polarity of one end of *A* by one of the rules given in § 59, *A* may be looked upon as a bar magnet, and the direction of the currents induced in *B* predicted as in the case of the experiment illustrated in Fig. 30. When the coils are one within the other (Fig. 33), one may think of the lines spreading out from and collapsing into coil *A* when the circuit is respectively made and broken, and the direction in which these lines cut the outer coil *B*. In experiment (*f*), when the iron core is inserted, many additional lines spread out from the inner coil and cut the outer coil. When the core is withdrawn, these lines collapse, and again cut the outer coil.

An easier but perhaps less complete way of predicting the direction of induced currents, follows on the law given in the next paragraph.

65. LENZ'S LAW. *In all cases of electro-magnetic induction, the direction of the induced currents is such as to tend to stop the motion producing them.*

66. FURTHER COMMENTS ON EXPERIMENTS IN § 61. We may apply Lenz's law to predict the direction of induced currents in certain cases, bearing in mind that to induce or set up an E.M.F. and a consequent current in an otherwise inert conductor, work has to be done.

In exp. (*a*), § 61 (Fig. 29), the direction of the induced current is such that the conductor *a b* tends to move across the field[1] in the reverse direction to that in which it is being moved, and it is in overcoming this tendency that work is done, the wire actually requiring more effort to move it up or down across the field, than if the field did not exist, though in this case the effort is inappreciable.

In exp. (*b*), § 61, the direction of the induced current is such as to create a momentary N. pole at the end of the coil nearest the magnet, on bringing the magnet up to the coil (or the coil up to the magnet): and a momentary S. pole on separating the coil and the magnet. In other words, on bringing the magnet up to the coil, and taking it away, work is done in bringing up the N. pole against the repulsion of the induced N. pole; and in drawing it away against the attraction of the induced S. pole.

In exp. (*c*), § 61 [*N.B. The reader should first go through* §§ 67 (*large print*) and 68], the circuits being stationary, when *K* is depressed, the lines of force due to current in *a b* cut *c d*, and induce a momentary reverse current therein. The lines due to this current in *c d* cut *a b*, and cause a direct E.M.F. to be set up in *a b*, so that the battery current is momentarily assisted. The *self-induction* (§ 67) of *a b* retards the current in *a b*, so that it does not rise all at once to its full value: *mutual induction* (§ 68)

[1] A current-carrying conductor tends to move of its own accord across any magnetic field in which it is placed (Chap. XIII.).

between $a b$ and $c d$ assists the setting up of the current in $a b$. In other words: the effects of self-induction in the primary circuit are, as a rule, lessened by the presence of a closed and otherwise inert secondary circuit, the momentary expenditure of energy thus saved from overcoming self-induction, being absorbed in setting up the induced secondary current.

On breaking the primary circuit at K, a momentary direct current is induced in $c d$, and this current tends to create an opposing E.M.F. in $a b$, which assists in bringing the current in $a b$ to zero. Self-induction prolongs the current to $a b$, while mutual induction between $a b$ and $c d$ tends to assist the stoppage of current in $a b$ on breaking circuit. In other words, when the primary circuit is alone concerned, the energy of the collapsing field goes to the production of an *extra current* (§ 67). When a secondary circuit is present, most of this energy is expended in setting up a momentary current in that circuit, and the extra current effect in the primary circuit is lessened.

This is the action of a copper tube when placed over a solenoid or electromagnet, or between the core and the coil of an electromagnet: it reduces the self-induction of the magnet and the extra current sparking at the key or other contact breaker in the circuit of the coils and battery, by having induced currents circulated in itself, these induced currents causing a momentary absorption of energy on the make and break of the primary circuit.

From what we have said, it should be clear how the energy necessary for the setting up the induced currents in the secondary circuit is derived from the primary circuit. It should be remembered that in the case of a direct current, such as that under consideration, the effects of self and mutual induction are only momentary, and occur on the making or breaking of the circuit. A very short time after making circuit, the current in that circuit will depend simply on Ohm's law.

When the circuits are moved relatively to each other, the explanation is as follows: when the key is kept down, and $a b$ is brought up to $c d$, work is done against the repulsion set up between the primary current in $a b$ and the secondary induced current in $c d$ (§ 69); when $a b$ is withdrawn, work is done against the attraction between the inducing and induced currents: this work representing the energy necessary for the setting up of the currents in the secondary circuit $c d$.

In exp. (d), § 61, we may again look on coil A as a bar magnet, having, say, a S. pole at its left-hand end. Then, according to Lenz's law, the momentary induced currents in coil B will be such as to create a S. pole at its end nearest A

when the current in A is started, or when A is approached: and a N. pole at that same end when the current in A is stopped, or when the distance between A and B is increased.

In exp. (*e*), § 61, we may apply the same arguments as with exp. (*c*), the wires being merely coiled up instead of straight.

In exp. (*f*), § 61, we may think of the adjacent ends or poles of the inner and outer coils. Inserting the iron core strengthens both poles of the inner coil, and the momentary current in the outer coil will be such as to give like poles at the corresponding ends. Withdrawing the iron core weakens both poles of the inner coil, and the current in the outer coil will then be in such a direction as to give unlike poles at its corresponding ends.

67. INDUCTANCE, OR SELF-INDUCTION. Inductance, or self-induction, may be defined as *the cutting of a conductor by lines of force produced by its own current.* When a current begins to flow along a circuit, it sets up a magnetic field around the conductor. This magnetic field, in being set up, reacts upon or cuts the conductor, and induces a momentary reverse E.M.F. in it. When the current flowing along a conductor is stopped, the magnetic field collapses, and in collapsing cuts the conductor, and in consequence another momentary E.M.F. is induced in the conductor, which is "direct," *i.e.*, in the same direction as the inducing current.

The effect of inductance is to momentarily oppose the setting up of a current in a circuit by reason of the opposing "reverse" E.M.F.; and to momentarily retard its "breaking" or cessation, because of the momentary "direct" E.M.F.

Inductance is not very noticeable in straight conductors, as the conductor cannot be so effectively cut by the lines as when it is coiled up. Also because the lines of force set up in a circuit are more crowded if the circuit is coiled up, and are increased in number if the coils have iron cores; inductance is always greatest in circuits containing electro-magnets, etc.

The sparks observed at the contact points in an electric bell, or when a circuit containing a magnet is broken, are principally due to the collapsing of the lines of force of the magnet, which, cutting the coils of wire, give rise to a momentary *direct* E.M.F., that sets up an *extra current* (§ 100).

The effects of inductance are noticeable in a circuit not only when a current is set up or stopped, but also when the current is increased, or diminished, or reversed; such increase, or diminution, or reversal, altering the number of lines of force passing through or interlinked with the circuit, and their direction, and therefore giving rise to momentary induced E.M.Fs. The unit of inductance is now called the *henry*, and has been called the *secohm* or *quadrant*.

Inductance is usually denoted by the letter L. If a coil has N turns, and a current C produces a flux F,

$$L=\frac{N\mathsf{F}}{C}$$

L is evidently the measure of the number of lines of force cut by the N turns when unit current is suddenly turned on or off, for if $C=1$ then $L=N\mathsf{F}$.

We have to consider the number of lines cut by the whole

circuit, *i.e.* N F, thus if a coil has 200 turns, and 2000 lines are set up, the total number of lines cut will be $200 \times 2000 = 400{,}000$.

To express L in henries we must divide the number of lines cut (N F) by 100 millions, for the cutting of one line (per sec.) represents the setting up of 1 C. G. S. unit of E. M. F., and the volt (or practical unit) being 100 million times the C. G. S. unit, must necessitate the cutting of 100 million lines (per sec).

Thus:—

$$L \text{ (henries)} = \frac{N\,F}{C \times 100 \text{ millions.}}$$

A *henry* may therefore be defined as the inductance in a circuit such that the sudden starting or stopping of 1 ampere of current causes 100 million lines to be cut by the circuit.

In a coreless coil L varies with the square of the number of turns in the coil, since each turn not only adds to the value of F, but also to N.

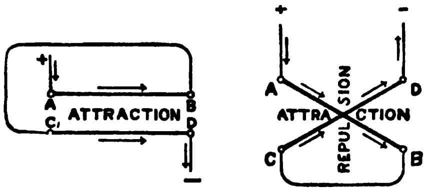
When a direct current is turned on through the coils of a magnet, the pull of the magnet gradually increases as the back E.M.F. of inductance dies away: when the current is steady, the pull is steady: when the current is stopped, the pull momentarily increases, owing to the momentarily induced direct E.M.F.

68. Mutual Induction takes place when neighbouring current-carrying circuits act inductively upon one another, and may be defined as *the cutting of a circuit by lines of force produced by a current flowing in another circuit.*[1]

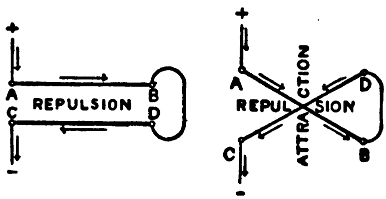
* 69. Attraction and Repulsion of Currents. Currents in neighbouring portions of the same or different circuits will attract each other if they flow in the *same* direction, and repel each other if they flow in *opposite* directions. Thus, in Fig. 35A the two

[1] Concerning inductance and mutual induction, see also Vol. II.

portions $A\,B$ and $C\,D$ will attract each other, while in Fig. 36A they will repel each other. If the wires cross each other, the attraction and repulsion between the various parts will tend to make them eventually close up like a pair of scissors: thus in Fig. 35B, the wires $A\,B$ and $C\,D$ will tend to shut up so that the ends $A\,C$



Figs. 35A & B. Attraction and Repulsion of Currents.



Figs. 36A & B. Attraction and Repulsion of Currents.

and $B\,D$ approach each other; while in Fig. 36B, $A\,D$ and $C\,B$ will approach. Referring to Fig. 35B, consider each wire as divided into halves at the point where they cross, and call this point X: then when we consider the statement made at the beginning of this paragraph and the directions of the current, it must be clear that attraction is set up between $A\,X$ and $C\,X$,

and also between $B\,X$ and $D\,X$; while repulsion takes place between $A\,X$ and $D\,X$, and between $B\,X$ and $C\,X$. The same argument may be applied to Fig. 36B.

The reason for the actions just explained will be understood from the following magnetic figures given by two neighbouring vertical current-carrying conductors (Figs. 37 and 38), the currents being in the same direction (either up or down) in the first case, and in opposite directions in the second case.

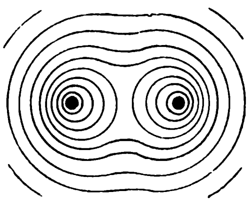


Fig. 37. Attraction of Currents.

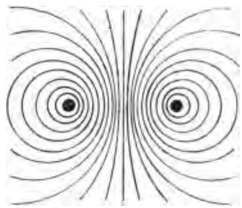


Fig. 38. Repulsion of Currents.

It is a property of lines of magnetic force running approximately in the same direction to tend to lie as far as possible side by side, and so follow the same circuit. Hence the merging of the two fields in Fig. 37. The lines-of-force then tend to shorten themselves, and in so doing draw the conductors together. In Fig. 38 the currents, and therefore the fields due to the two wires, are in opposite directions; the two fields are consequently distorted, and in endeavouring to place themselves symmetrically with regard to their respective conductors, the latter are forced apart.

These actions may otherwise be explained as follows, considering in each case the space between the conductors. When adjacent fields run in opposite directions (Fig. 37), the lines of each will alter their shape so as to run as far as possible side by side, and in the same direction. When adjacent fields run in the same direction (Fig. 38) the lines will mutually repel one another. It follows from this that there is repulsion between the lines of any field.

The reader should refer to Fig. 12 as regards the direction of the field round a current-carrying conductor.

This property of attraction and repulsion of currents, due to the interaction of their fields, is similar to that which takes place when a current-carrying conductor is placed in the field of a magnet, under which circumstances the conductor will experience a *magnetic drag*, and will tend to travel across the field. (Chap. XIII.)

CHAPTER IV.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Whenever a current flows through a conductor, a magnetic field is set up round the conductor. Conversely, when an independent magnetic field is brought up to a conductor, a momentary E.M.F. is set up in that conductor. Explain these effects.

*2. In how many ways could you induce a current in a conductor? Which is the best of the methods you describe, and why?

3. Give Faraday's law of electro-magnetic induction.

4. What is Lenz's law, and how could you use it to predict the direction of the induced currents in experiments (*a*), (*b*), and (*d*), § 61?

5. Referring to experiments (*c*) and (*d*), § 61, show clearly that the effects obtained therein are in accordance with the general law (i.) of electro-magnetic induction (§ 62).

*6. What is the rule for finding the direction of the induced current when a conductor is moved across a magnetic field?

*7. Show by sketches, and the application of the left-hand rule (§ 63), that the current induced in a conductor when moved *down* in front of a N. pole, is in the same direction as the current induced when the conductor is moved *up* in front of a S. pole. *N.B.* The observer is supposed to face the pole in each case.

8. What do you know of inductance?

9. Why is the inductance in any given length of wire greater when the wire is coiled up than when it is straight?

10. Could you coil a length of wire up in such a manner that it should have no inductance? If so, how?

11. What is the unit of self-induction or inductance, and how is it estimated?

12. Distinguish between self-induction and mutual induction.

13. Why does an electro-magnet spark on breaking the exciting circuit? [Ord. 1895.]

*14. Explain clearly in what way two neighbouring current-carrying wires tend to act upon one another, and why there is in some cases attraction, and in others repulsion.

*15. Give a theory for the "magnetic drag" subsisting between two neighbouring current-carrying conductors.

16. How are the pull and self-induction of an electro-magnet connected? [Ord. 1895.]

17. How does the slipping of a copper tube over the core lessen the spark of an induction coil? [Ord. 1895.]

18. When a metal tube is used in the manner described in the preceding question, its temperature rises. Why is this?

CHAPTER V.

The figures refer to the numbered paragraphs.

* 70. INTRODUCTION. This chapter will treat of electric bells, indicators, and contact-makers; the principal methods of joining them up in circuit, and the batteries employed. The subject of electric bell fitting is a far-reaching one, but it will be possible in this single chapter to explain and illustrate the general principles which underlie such work, commencing with a description of the types of cell in most common use.[1]

* 71. THE LECLANCHÉ AND SIMILAR CELLS. This is the cell most extensively used in electric bell work as yet.

[1] The Author is indebted to the General Electric Co. for Figs. 40, 42, 45, 46, 47, 48, 49, 50, 51, 54, 55, 57, 59, and 65: to Messrs. Sax & Co. for Figs. 39, 52, and 58: and to Le Carbone, the Birmingham Telegraph Factory, and the Electrical Co., for Figs. 41, 56, and 63 respectively.

In its ordinary form it consists of an outer glass vessel containing a solution of sal ammoniac (ammonium chloride), and a zinc rod. In the centre of the outer vessel stands a porous pot of unglazed porcelain, containing a carbon plate tightly packed round with small lumps of crushed carbon and black oxide of manganese,

FIG. 39. Ordinary Leclanché Cell.

(otherwise called peroxide of manganese or manganese dioxide,) in equal proportions.

The carbon plate sometimes has a lead cap cast on to it, in which is imbedded a piece of screwed brass wire carrying a brass nut: this forms the positive pole of the cell. In the best cells, the cap supporting the terminal on the carbon is made of carbon also, instead of lead,

and the injurious formation of white lead which often takes place with lead-capped carbons is thereby stopped. The zinc rod has a piece of covered copper wire soldered to its top end, the naked end of the wire forming the

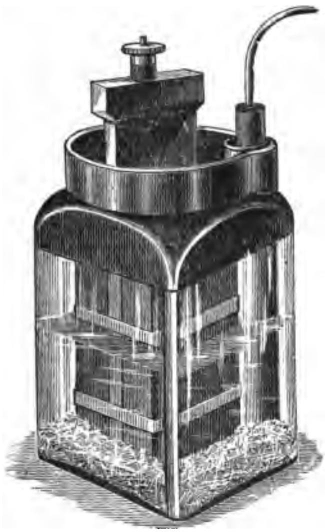


Fig. 40. Agglomerate Leclanché Cell.

negative pole. Fig. 39 illustrates the above-described form of cell.

The Leclanché cell is eminently suitable for ordinary electric bell work, where current is only required for a very short time, at long intervals. There are several modifications of the form just described, among which may be mentioned the agglomerate-block, and the

Lacombe cell. In the first of these the porous pot is sometimes dispensed with, and in both the internal resistance of the cell is very much lessened. In the *agglomerate-block Leclanché cell* (Fig. 40), the carbon and manganese mixture is crushed fine, mixed with some cementing composition, and formed under great pressure into blocks, which are afterwards held against the sides of the carbon plate by india-rubber bands. These bands also sometimes carry rings in which the zinc rod is held, for it is necessary that the latter should not touch either the carbon plate or the agglomerate blocks. As, however, impurities detached from the agglomerate blocks sometimes settle on these india-rubber bands and set up local action, it is better to place the zinc rod in a small porous pot (Fig. 40), which may be perforated with holes so as to offer as little resistance as possible.

The *Lacombe-Leclanché* or "*Carporous*" *cell*, a section of which is shown in Fig. 41, consists of a perforated cylinder of carbon *A*, mounted on a glass base *C*, which also carries the inner perforated cylinder of porous porcelain *B*, the space between these being filled up with small lumps of carbon and peroxide of manganese *M*. The zinc rod *Z* stands in the inner porcelain cylinder, the latter carrying an insulating cap *N* to prevent the zinc rod by any chance from touching the carbon top of the carbon cylinder. In the latter is held a piece of tapped brass wire carrying a washer *W* and nut *N'*.

The *Leclanché-Barbier cell* is very similar in out-

ward appearance to the Lacombe-Leclanché cell. It is not the same, however. The zinc rod is hung by a wooden cap in the centre of a cylinder of compressed carbon and manganese dioxide, which in its turn is supported from the neck of the outer glass vessel, so that it does not touch the bottom. The cylinder is open at the bottom and the solution of sal ammoniac

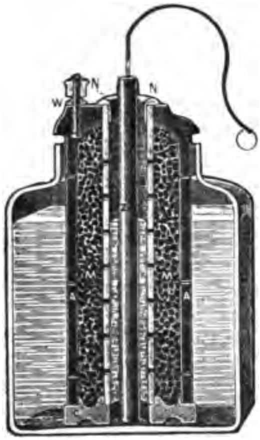


Fig. 41. Lacombe-Leclanché Cell.

has free access to the space between the zinc and the agglomerate cylinder. The Leclanché-Barbier cell is also made in the form of a dry cell.

* 72. Dry Cells. Though these are known under many different names, such as the *E.C.C.*, the *Obach*, the *E.S.*, the *Hellesen*, etc., according to the makers, they are all practically the same. In a containing

vessel, generally of cardboard, is placed a zinc cylinder with wire attached, and in the middle of this stands a carbon plate or rod, the space between being filled with a jelly-like composition. Sometimes the zinc itself forms the outer cell, but in such case the insulation of the battery is not so good. According to one formula, the zinc is coated to the thickness of ¼ inch with a paste of plaster-of-paris, sal ammoniac, and water in the proportion of 25, 10, and 55 parts by weight respectively. The carbon is then put in, care being taken that it does not touch the zinc, and the remaining space filled with the following mixture :—

	Parts by weight.
Powdered carbon	75
Coarsely powdered peroxide of manganese .	10
Zinc sulphate	5
Sal ammoniac	15
Glycerine	2

Water sufficient to make a stiff paste.

The cell is afterwards sealed up with melted pitch, vent holes being provided by inserting two pieces of thick wire, and removing them when the pitch is cold. The compositions used in the different makes of cell are kept secret, but the above will give fairly good results. It will thus be seen that these so-called dry cells are really a modification of the Leclanché cell, with the addition of zinc sulphate. The plaster-of-paris and glycerine serve to make up the paste, but do not play any part in the chemical action of the cell. These cells may be used for all purposes where

the current is only wanted occasionally, and they possess great advantages over the ordinary Leclanché cell, in that there is no liquid to spill or leak away, and they may be placed in any convenient position, upright or on their sides.

Fig. 42 shows a battery box fitted with terminals, and containing 3 E.C.C. cells. Such boxes ought to be

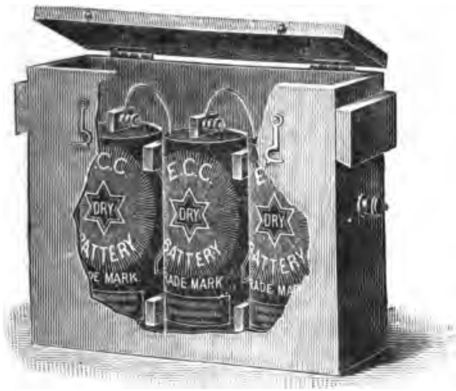


Fig. 42. "E.C.C." Dry Battery.

used with all batteries, but air-holes should be provided.

* 73. CHARGING AND WORKING OF CELLS. Any form of "dry cell" is of course all ready for work. In charging either of the four forms of Leclanché cell described above, first drop in the sal ammoniac crystals, the quantity depending on the size of the cell; for the larger size about 5 oz., for the medium size about 3 oz., and for the smallest size about 2 oz. Then fill the glass cell three-quarters full with water.

taking care not to wet the edges or terminals. When this has been done, the agglomerate, Lacombe, and Leclanché-Barbier cells will be ready for work, but the ordinary form (Fig. 39) requires time for the liquid to soak through the porous pot.

When inspecting cells already at work, their condition and requirements will be indicated as follows: (*a*) If any of the zincs are eaten away, renew them. (*b*) If there is a deposit of crystals on the zincs, it must be scraped off. (*c*) If the zincs are black in colour, it denotes that the battery is being overworked, and that probably there is a leakage or short circuit somewhere, which should at once be seen to. (*d*) If the solution is low, add fresh water, and also more sal ammoniac if there is none at the bottom of the jar. (*e*) If the solution is cloudy, more sal ammoniac is required. (*f*) If "creeping" has set up over the edge of the outer jars, the latter must be removed, washed, well dried, and the edges carefully greased round, with vaseline, for instance. (*g*) If white lead has formed to any great extent around the lead cap on the carbon, a new carbon should be inserted, which is best done in the case of the ordinary form of cell by putting in a new porous pot and carbon complete.

* 74. CONNECTING-UP, E.M.F., AND RESISTANCE OF CELLS. Cells are generally connected up "in series" to form a battery, *i.e.*, the zinc of the first cell is connected with the carbon of the second cell, and the zinc of the second cell to the carbon of the third cell, and so on to the end (Fig. 42). In diagrams, one cell, of

whatever make, is denoted by the left-hand symbol in Fig. 43, the short thick line representing the zinc, and the long thin line the carbon, or whatever forms the + pole. Fig. 43 also shows three cells joined up "in series."

The E.M.F. of all cells of the Leclanché type, no matter what size they may be, is about 1·4 volts per cell; so that the E.M.F. of a battery is got by multiplying 1·4 by the number of cells in series. Thus the E.M.F. of a 6-cell battery will be 8·4 volts.

The internal resistance of the cells is a very variable quantity, depending on the size, construction, and state

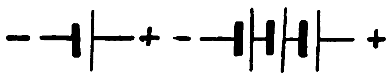


Fig. 43. Symbols for Cell and Battery.

of the constituents of the cell. The larger a cell, the less its resistance. The internal resistance of the ordinary size porous pot Leclanché, under average conditions, is about one ohm: that of the ordinary size agglomerate Leclanché being about ·6 ohm. The resistance of the Lacombe cell is probably less than ·5 ohm. The resistance of dry cells, which are made in many different sizes, varies from ·3 to 7 or 8 ohms.

* 75. Ordinary Electric Bell. Fig. 44 illustrates the ordinary *trembling* or *vibrating electric bell.* *F* is the cast-iron frame to which the working parts of the bell are fixed. *I C* are two soft iron cores screwed into this frame, and carrying bobbins of wire *B B*. *A* is the

soft iron armature supporting the stem and hammer *H*. *A* is held to *F* by the steel spring *S*, the lower extremity of which should be tipped with platinum *P*. *C S* is a contact screw and stud fixed to, but insulated from, the foot of the iron frame. *C S* is connected by a wire underneath, with the right-hand terminal *T′* of the bell. When the magnet cores *I C* are not magnetised by the passage of the current through the coils, the

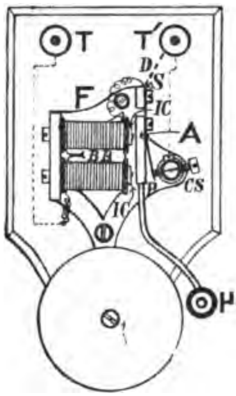


Fig. 44. Electric Bell.

tip of the spring *P* bears against the end of the contact screw *C S*, which should also be tipped with platinum. The reason for this is, that when the bell is working, and each time the spring is drawn away from *C S*, a small spark occurs, which tends to oxidise and tear away the contact points. Platinum being a very inoxidisable and infusible metal, always presents a clean surface of contact.

The working of the bell is as follows. The current entering, say at the terminal *T*, traverses the magnet coils, and thence passes to the framework at *S*: from there it passes down the spring to *P* and *C S*, and so to the terminal *T′*. As soon as this occurs the iron cores *I C* become magnetised, attract *A*, and *H* strikes the bell. In consequence of the attraction of *A* the circuit is broken at *P*, the current is stopped, the magnet demagnetised, and the force of the spring *S* brings its tip once more against *C S*, when the circuit is again completed, the armature attracted, and the bell struck. Thus the bell hammer *H* vibrates rapidly to and fro as long as current is passed through the bell.

It makes no difference in the working of any ordinary form of electric bell which way the current flows through it.

* 76. The Single-stroke Bell. If the terminal *T′* (Fig. 44) is connected with the framework, as indicated by the dotted line *D*, instead of with the contact stud *C S*, the bell becomes a *single-stroke bell*, *i.e.*, one tap only of the hammer is given every time the push or other contact-maker completes the circuit. *C S* then acts merely as a stop to prevent the armature flying back too far.

The adjustment of the armature and hammer in a single-stroke bell differs from that in a trembling bell. In the latter, the hammer should strike the gong without the armature touching the magnet poles. In the former, the armature should touch the magnet poles first, so that the hammer springs forward by its own

momentum, strikes the bell, and then springs back, even though the armature be still held close up to the poles. A clear stroke of the bell is the result.

* 77. Different forms of Bells. Electric bells are made in many different forms; in some, the bell itself is made to contain or to act as a cover for the works; in others, called vertical bells, the hammer stem stands upright, and the bell itself is fixed on the top of the wooden case. Again, there are different methods of connecting up the coils and contact screw with the

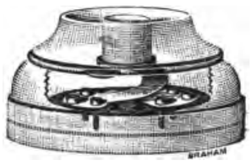


Fig. 45. Push.

Fig. 46. Push Springs.

terminals, and of mounting the armature. Sometimes the contact screw is dispensed with, its place being taken by a spring. Some bells have attachments for making the vibrations of the bell hammer slow, as the rapid vibrations of the ordinary bell are sometimes rather irritating. However a bell may be constructed, the principle will be understood from what has already been said.

The continuous-ringing bell is explained in § 83.

* 78. Pushes and other Contact Makers. The most common form of contact maker is the push,

which is too well known to need much description. Fig. 45 shows a push with a view of the springs inside. The latter are shown separately in Fig. 46. The parts where these springs come into contact should be tipped with platinum as shown, for reasons already given in the description of the electric bell. All dotting or "end" contacts (which are used in most electric bell apparatus), as distinguished from "rubbing contacts" where the two contact surfaces rub over one

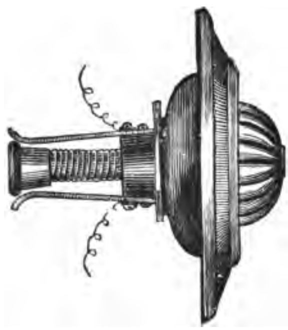


Fig. 47. Pull.

another and so keep clean and bright (as in switches), require to be platinum tipped. On the score of expense, silver is often substituted for platinum, but it is not quite so efficient.

Fig. 47 illustrates a *pull.* Two flat metal springs mounted on an insulating block of ebonite or paraffined hardwood, are connected with the ends of the circuit. When the handle is pulled out, a brass ring at the end of the handle bar is drawn between the ends of the

springs, and so completes the circuit. A spiral spring on the handle bar forces the latter back to its normal position when released by the hand. In this device we have a very good rubbing or sliding contact, and there is no necessity for the use of platinum.

Fig. 48. Double-contact Push.

In some circuits, for instance in that given in Fig. 67, it is necessary for the push to have two contacts, a top and a bottom; thus three wires are connected to the push: calling these *a*, *b*, and *c*, sup-

Fig. 49. Switch.

posing *a* is connected with the middle or movable spring, *b* with the top contact, and *c* with the bottom contact; in the ordinary position of the push *a* is connected with *b*, but when the push knob is depressed *a* is disconnected from *b*, and connected with *c*. Such a

push, which is called a ***morse, two-way***, or ***double-contact push***, is shown in Fig. 48.

Fig. 49 shows a simple or ***one-way switch*** used for opening or closing a circuit for any length of time. In the position illustrated, the switch is "off." If another contact and terminal were placed to the left-hand side of the contact lever, the switch would become a ***two-way*** one. The use of switches will be explained later on, in dealing with electric circuits. (Figs. 69 and 71.)

One of many forms of ***burglar contact*** or ***alarm*** is shown in Fig. 50. It consists of a brass plate, to the back of which is secured a steel contact spring, and a small contact plate insulated on an ebonite block. One end of the circuit is connected with the insulated contact plate, and the other with the spring. A hole in the brass plate allows a marble to project partly through it, the marble being prevented from falling out of position by the spring behind it. This device is adapted for doors and windows, it being let in flush with the window frame or door jamb. In the former case, when the window sash is lowered, the marble is pushed in and the contact spring forced away from the contact plate; when the window is opened, the marble is allowed to project and the circuit is closed. In this, and in the door-trigger about to be described, platinum contacts are obviously necessary.


Fig. 50. Burglar Contact.

Fig. 51 shows a *two-way door-trigger*, which closes the circuit and rings a bell when the door is either opened or shut. Its construction is clearly shown. There are two steel contact springs; the bottom one carries an ebonite knob, against which the top of the door presses as it opens or shuts, the trigger being screwed to the top of the door frame. The top spring is mounted on an insulating ebonite block. When the knob on the bottom spring is forced upwards, the two springs come together, and the circuit is completed.

Of *heat* or *fire alarms* there are many varieties.

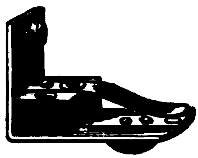


Fig. 51. Door Trigger.

Some are constructed on the principle of the thermometer, the mercury (which is connected with one wire), as it rises, making contact with a wire let into the top of the tube. Others, again, have a compound metal spring, which warps on the application of heat, owing to the unequal expansion of the two metals, and so makes contact with a stud (Fig. 71). The most sensitive are undoubtedly those which are actuated by the expansion of air in an air-tight chamber. One acting on this principle, made by Messrs. Sax & Co., is shown in section in Fig. 52. *A* is a box made of sheet iron, to the front of which is fixed an air-tight copper

chamber *B*, the upper side *D* of which is corrugated and carries a contact *C*. Mounted inside, but insulated from the iron box, is a spring carrying a contact screw *E*; the end of the spring rests on a little insulating block, and under normal conditions, the point of *E* and the contact surface *C* are just clear of each other. The air-chamber *B* is hermetically sealed, and air having been partially withdrawn, the diaphragm *D* sinks slightly inwards. As the temperature rises, *C* is gradually forced outwards until it touches *E*, when the bell rings. The same thing will happen if the

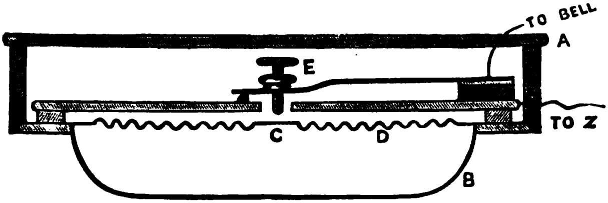


Fig. 52. Fire Alarm.

chamber becomes damaged, as air will rush in, and force the diaphragm against the contact screw. A continual check is thus kept on the proper working of these alarms. The iron box *A* is not air-tight, but serves as a support and protection for the diaphragm and contacts, and for convenience of fixing.

There are many other forms of circuit closer or contact than those described here; for instance, *pear pushes*, *pressels*, *bedroom pulls*, *outdoor pushes*, *lever pulls*; *floor*, *curtain*, *and window blind contacts*, and numerous other forms of burglar alarms and door-

triggers. They all act on the same principle, of bringing two contact surfaces together when actuated, and so closing the circuit; and can therefore easily be understood from what we have already said.

* 79. MAYCOCK'S RULE FOR ELECTRIC BELL WIRING. All the wires in any electric bell or signalling circuit, no matter how complicated, may be classified under three heads :—

(*a*) + *battery wires*, or wires leading direct to the + pole of the battery.

(*b*) − *battery wires*, or wires leading direct to the − pole of the battery.

(*c*) *Connecting wires*, or wires passing between apparatus, (as from push to indicator, fire alarm to bell, etc., etc.,) and not connected directly with the battery.

The importance of being able to distinguish between these at a glance will be understood by all who have had any experience with electric bell fitting, as thereby not only is the progress of the work, and subsequent repairs or additions to it greatly facilitated; but the initial planning out of a "circuit diagram" of the work, of which every bell-fitter should be capable, is far easier to arrange, and much more certain to be correct.

The only rule which fulfils these conditions is that devised some years ago by the Author, and is as follows :—

In wiring, all wires leading from the + pole of the battery (+ battery wires) to any push, etc., should be of

a plain bright colour (preferably white, yellow, or red): all wires leading direct to the – pole of the battery (–battery wires), should be of a plain dark colour (preferably black): and all wires running between apparatus (connecting wires), should have a covering in which two or more colours are woven.

In drawing circuit diagrams, + battery wires should be shown in red pencil or red ink, or, if these are not available, by thin black lines; – battery wires by black ink or thick black lines, and connecting wires by dotted lines. (See following circuit diagrams.)

* 80. Simple Electric Bell Circuit. Fig. 53 shows

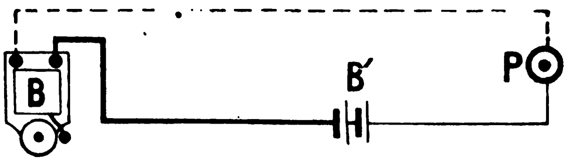


Fig. 53. Simple Circuit Diagram.

a circuit comprising a battery *B′*, a bell *B*, and a push or other contact *P*. It serves to illustrate a simple application of the foregoing rule.

* 81. Indicators. Most *electric indicators* may be classified under three heads:—

(*a*) Mechanical replacement.

(*b*) Self-replacement, or pendulum, or vibrating.

(*c*) Electrical replacement.

There are a great number of varieties of each class, but we must be content with referring to a single good example of each

Fig. 54 is a very much used form of *mechanical replacement indicator*, or indicator which when deflected by a current, has to be replaced by hand. The working parts are mounted on a frame stamped out of sheet brass. To the left is fixed a horseshoe electro-magnet with one coil (similar to Fig. 24), the two iron cores being screwed into the brass frame, with a yoke-piece of sheet iron interposed. Just above the poles of this magnet is a sheet iron armature fixed to one end of a horizontal pivoted lever. A second pivoted lever

Fig. 54. Mechanical replacement Indicator.

carries the flag or indicator, and in the position shown has just been released. When replaced, this second lever engages with a catch seen at the right-hand end of the horizontal lever, and is thereby held up until a current passes through the magnet, when, the catch being lifted up, the lower lever is released and the flag falls. For ship, train, or other work where there is vibration or jolting, the top lever is steadied by a spiral spring, as seen in the figure, this preventing the flag being shaken down, except when a current passes. For

ordinary work this spring is dispensed with, the right-hand end of the lever being heavier than the armature end.

Fig. 55 illustrates a good form of *pendulum* or *vibrating indicator.* The magnet has only one coil and core, but the frame being of sheet iron, the suspended

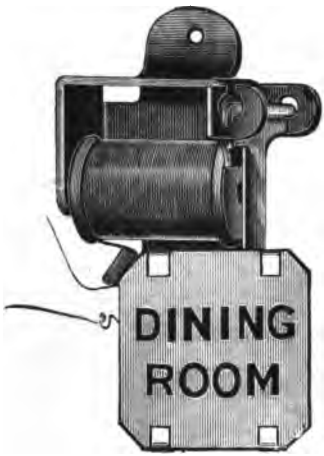


Fig. 55. Self-replacement Indicator.

armature practically forms the other pole of the magnet, so that the magnetic circuit is fairly complete. When a current passes, the armature and indicator flag are drawn over to the left, and continue to swing backwards and forwards for some seconds after the current has stopped.

Fig. 56 represents an *electrical replacement indicator.*

The movable portion carrying the flag is made of hardened steel, and is magnetized, thus forming a permanent magnet. This, and the two coils and iron cores, are mounted on a brass back plate. The coils and cores form separate bar electro-magnets, one of which (the right-hand one) we may call the deflecting magnet, and the other the replacing magnet.

Fig. 56. Electrical replacement indicator.

Suppose the front pole of the permanent magnet armature (called a *polarized armature*) is N., and the back pole S., the current from the distant push must flow round the right-hand magnet so as to make its front end N., and its rear end S. The poles of the fixed electro-magnet will then repel the poles of the magnetized armature, and the indicator flag will move

over to the right. To replace it, current is sent from the *replacing push* in such a direction that the poles of the left-hand electro-magnet repel those of the polarized armature, and the latter once more moves back to its normal position. This action will be better understood later on (Fig. 72).

Indicator movements are mounted in a box, the front of which has as many windows or transparent openings as there are indicator movements. Thus Figs. 57 and 58 show respectively 5 and 2 "number"

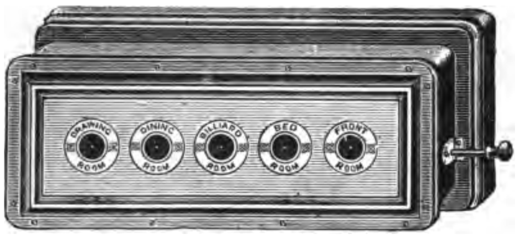


Fig. 57. Five-no. Indicator.

mechanical replacement indicators. The movements in Fig. 58 are of a different pattern to those shown in Fig. 54. The armature is pivoted at one end, and the other, falling by its own weight, forms a catch, and locks the flag-carrier in the position shown. When current passes, the armature is drawn up, and the flag falls in front of the fixed white disc, thus indicating from which room the signal has come. In both patterns (Figs. 57 and 58) any flag which has been released is replaced by pushing in the knob at the right-

hand end of the indicator case, the internal arrangement being clearly shown in Fig. 58.

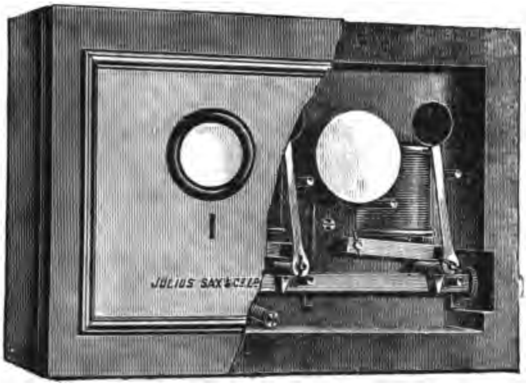


Fig. 58. Two-no. Indicator.

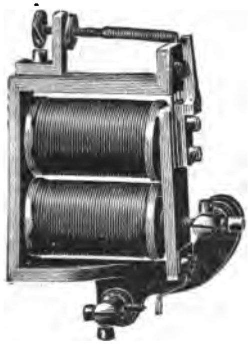


Fig. 59. Relay.

* 82. RELAY. A *relay* may be defined as a sort of electric push: in other words, when a current flows

round its coils, and its armature is attracted, two contact surfaces are brought together and close another circuit. There are many different patterns of relay, a simple form, well adapted for bell work, being shown in Fig. 59; a diagram of the same, mounted on a wooden base and showing the connections, being given in Fig. 60.

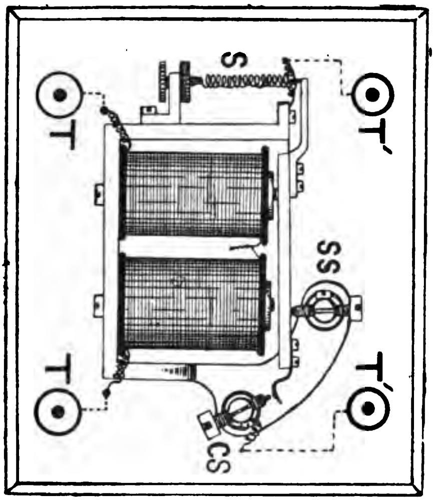


Fig. 60. Diagram of Relay.

The coils, armature, back-stop, and contact stud are mounted on an iron frame very similar to that used in an ordinary bell (Fig. 44). The armature is more delicately mounted however, its spring being very thin, and perforated (as seen in Fig. 59) to still further reduce its stiffness. A fine helical spring *S*

and thumb-nuts enable the tension on the armature to be adjusted to a nicety. The stud and screw *S S* serve merely as a back-stop, while *C S* is a contact stud insulated from the base. The ends of the coils are connected with the terminals *T T*; while the top right-hand terminal *T′* is joined to the frame work, and is thus in connection with the armature contact spring; the contact stud *C S* being joined to the bottom right-hand terminal *T′*. The armature being very lightly adjusted, a weak current flowing in and out by the terminals *T T* is sufficient to attract it, and the circuit connected with *T′T′* is thus completed.

The uses of relays are very many; but if we explain one, their adaption in other cases will be readily understood. In ordinary electric bell work relays are generally used with indicators. With any ordinary indicator, such as those shown in Figs. 66 and 72, the current has to go from the battery to the distant push, thence through the indicator coil and bell, and so back to the battery. There are two objections to this arrangement: *firstly*, in the case of a large building, such as a mansion or hotel, the resistance of the wire on the indicator coils and that on the bell coils, added to the great length of wire leading to and from the push, necessitates the employment of a comparatively large number of cells in order to get a sufficiently strong current through to ring the bell. *Secondly*, when it is remembered that in the ordinary arrangement the current passing through the bell is the same as that passing through the indicator, and that the "make"

and "break" of the former renders the current very unsteady, a larger number of cells has to be used than if a steady current were passed through the indicator movements; the working of the latter being a great deal more reliable with a steady than with an unsteady current.

Fig. 61 illustrates the above remarks. *P* is the distant push, *I* the indicator movement coil, *R* the relay, *C* the relay contact, *B* the bell, and *B′* the battery. When *P* is pressed, a steady current flows

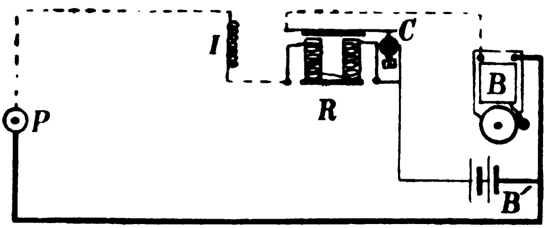


Fig. 61. Relay Circuit.

from the battery through *R* and *I*, and so back to the battery. The indicator is actuated, and the relay contacts are brought together, thus permitting a *separate* strong current to flow from the *same* battery direct through the bell. Immediately the push is released, the relay contact is broken, and the bell stops ringing. Sometimes two separate batteries are used, one in the relay circuit, and the other in the bell circuit. If the relay is placed with its armature in a vertical position, as shown in Figs. 59 and 60, and not as in Figs. 61 and 73, there is less chance of dust, etc., getting between the contacts.

* 83. CONTINUOUS RINGING BELL. *A continuous-ringing* or *continuous-action bell* is one which, when set ringing, keeps on until stopped by pulling a cord attached to a movable lever. Such a bell is shown in Fig. 62. The construction is much the same as that

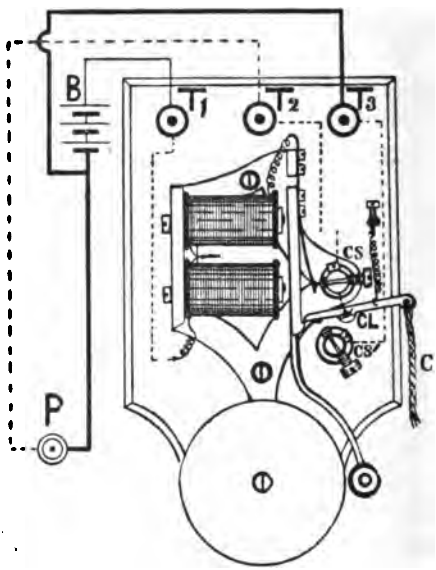


Fig. 62. Continuous-ringing Bell.

of an ordinary bell, except that there is an extra contact stud CS' besides the ordinary one CS, a contact lever CL, and a third terminal T_3. The armature is extra long, and has a slight projection at its lower end, on which the extremity of the contact lever rests when

in its normal position. When the armature is attracted, CL is released, and the force of the spiral spring at its right-hand end brings its left-hand end (which is tipped with platinum,) against the point of the lower contact screw CS'; when the bell will continue ringing until the cord C is pulled, and the contact between CL and CS' broken.

Such a bell is useful in a variety of cases, and we will explain how it is joined up in a simple circuit. B is a battery, and P the distant push, burglar alarm, fire alarm, or other contact maker. When contact is made at P, the current flows *viâ* T_1 through the coils and CS to T_2, through P, and back to the battery. Directly the armature is attracted, CL drops on to CS', and the current can then flow from T_1 through the coils to CS, thence *viâ* CL, CS', and T_3 back to the − pole of the battery, and the bell will continue ringing until CL is replaced.

* 84. Magneto Generator and Bell. A magneto-bell is one which is worked by an alternating current derived from a *magneto machine* or *generator* (sometimes called the *ringer*), which latter is, in fact, a small alternator or alternate-current dynamo, having permanent field magnets, and a shuttle-wound armature (Chap. VIII.). If a coil of fine wire wound on an iron bobbin be quickly rotated in a strong magnetic field, a rapidly alternating current will be generated, which current may be led to the outer circuit by suitable connections. A view of a magneto machine is given in Fig. 65. In this case, three permanent magnets

have their like poles united by soft iron polepieces, between which the armature is pivoted. A handle outside the case rotates a large cogged wheel, which gears into a smaller one on the coil or armature shaft. Thus the latter is rapidly rotated when the handle is turned at a moderate speed. A magneto bell and automatic switch, such as is used in telephone work, are shown on the cover of the case; but these need be no further considered, except that it may be pointed

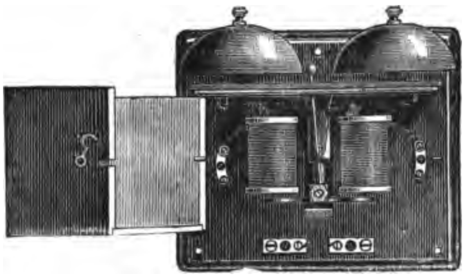


Fig. 63. Magneto Bell.

out that the bell (Fig. 65) differs slightly from that illustrated in Figs. 63 and 64, which we will now proceed to describe.

Fig. 63 shows a magneto bell, and Fig. 64 is a diagram which will enable its action to be understood. There are two coils and cores *c c′* (Fig. 64) mounted on a yokepiece *Y*, the whole forming an ordinary horseshoe electro-magnet. Below is pivoted a light armature *A*, carrying a stem and hammer *H*, which strikes the bells when it moves to and fro. A light spring,

rivetted at its middle to the centre of the armature, bears on the two poles, and tends to keep the armature horizontal. This is shown at *Sp* in the figure, but it is not absolutely essential. Arranged so that its poles come opposite the middles of the yokepiece and armature respectively, is a permanent horseshoe magnet *NS*. The effect of this is to magnetize the magnet cores and armature by induction as follows: the N. pole of the permanent magnet induces south polarity at the middle part of the yoke s'', and north polarity at the

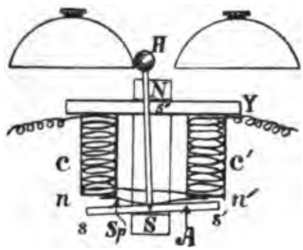


Fig. 64. Diagram of Magneto Bell.

poles of the electro-magnet, as at $n\,n'$; while the S. pole of the permanent magnet induces north polarity at the middle of the armature, and south polarity at its two ends $s\,s'$. The armature is thus polarized, and its direction of movement depends on the direction of the current. Suppose a current flows round the magnet in such a manner as to make the pole of c north and that of c' south; the induced N. polarity n is strengthened, while that at n' is destroyed, the pole for the time being S.: the right-hand pole of the armature

will thus be repelled, while the left-hand pole will be attracted, and the hammer *H* will move to the right. If now the current in the coils is reversed, so that *c* is S. and *c′* N., the armature will move over the other way. Thus the hammer will vibrate once to and fro with every complete alternation of the current. As we have said before, the polarization of the armature

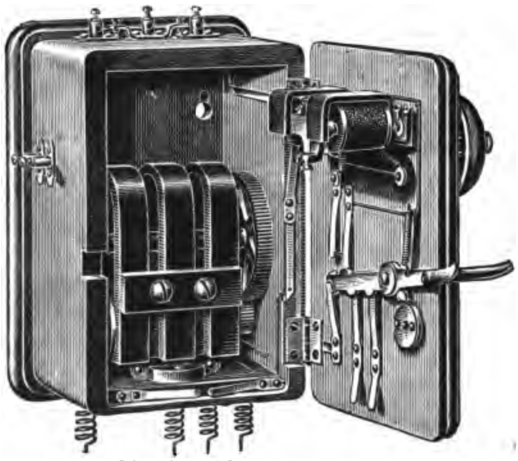


Fig. 65. Magneto Generator

enables it to change its movement with changes in the direction of the current; while the polarization of the magnet cores, which, as we have seen, can be readily overcome by the current in the coils, renders the magnet more susceptible to the rapid changes in the direction of the current. Obviously a magneto-bell will not continue to ring if a direct current be passed through it.

* 85. CIRCUIT DIAGRAMS. Having briefly described the construction and working of the principal kinds of electric bell apparatus, we will conclude this chapter with some *circuit diagrams*, showing the manner in which apparatus is connected up in circuit. A simple circuit, illustrating the connection of a battery, bell, and push, has already been shown in Fig. 53.

Fig. 66 illustrates a 3-no. mechanical replacement or pendulum indicator working from 3 pushes, and connected with a bell, and a 3-cell battery. The internal

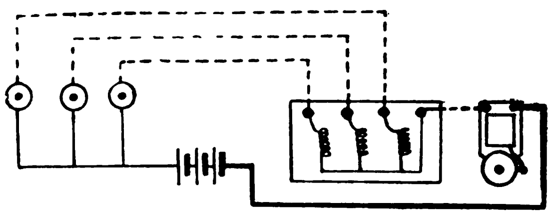


Fig. 66. Circuit Diagram.

connections of the indicator will be clearly seen, the short spiral lines representing the magnet coils of the indicator movements. The bell is often fixed to the indicator frame, but this makes no difference in the connections.

Supposing it is required to connect two places A and B, so that A may ring B's bell, and *vice versâ*, and suppose there is a battery at each place; then, if morse pushes (Fig. 48) be used, the connection may be made as shown in Fig. 67, with two wires only; or with one wire and Earth return, *i.e.*, with the return wires

soldered to the water pipes, so as to lead the current back through the Earth. To do the same thing with ordinary pushes would require three wires between the two places. Two places may be connected so that either can ring the other's bell, with a *battery at one station*

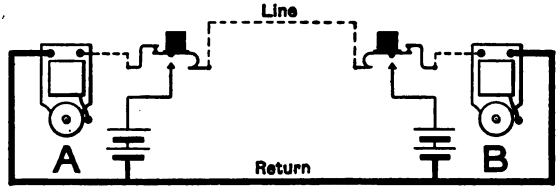


Fig. 67. Circuit Diagram.

only, with ordinary pushes, as shown in Fig. 68. Fig. 69 illustrates how either of two bells *A* and *B* may be rung from one battery by means of a two-way switch *S*. There are many cases in which such an arrange-

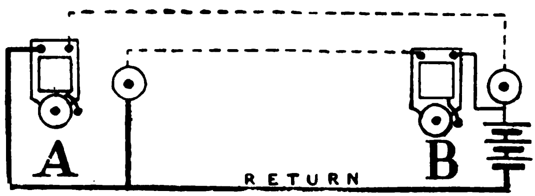


Fig. 68. Circuit Diagram.

ment is useful; and in some it might be necessary to insert a push between the switch and the battery.

When two or more ordinary trembling electric bells are required to be rung at the same time, from one battery and push for instance, the bells must be joined

up in parallel, so that the current divides between them instead of going through them one after the other, as would be the case were the bells connected in series. When we consider the action of a trembling bell and think of two such joined up in series, it is evident that, unless they made and broke circuit at exactly the

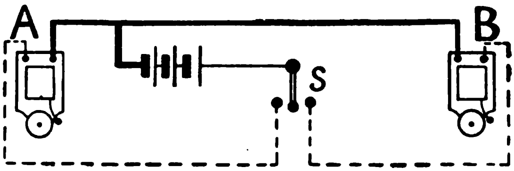


Fig. 69. Circuit Diagram.

same rate (a practically impossible condition), they would either work very jerkily and weakly, or not at all. Fig. 70 shows 3 bells joined up to ring from one push *P*. There are two or three special forms of trembling

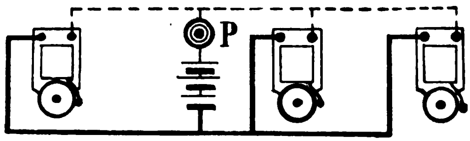


Fig. 70. Circuit Diagram.

bells adapted for series working, but space will not admit of their description. Single-stroke bells may be connected in series, since they do not break the circuit.

Fig. 71 shows 2 burglar alarms and 2 fire alarms connected up with a bell and battery. A switch *S*, of the kind shown in Fig. 49, is introduced into the circuit, so

that the latter may be broken in the daytime, when doors and windows are being constantly opened and shut. In an actual installation, the fire and burglar alarms would not be put in the same circuit as shown

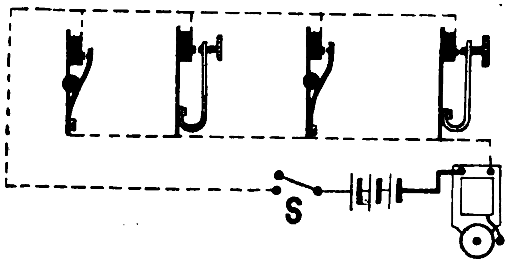


Fig. 71. Circuit Diagram.

in Fig. 71, because, while it is necessary during the daytime to cut the burglar alarms out, the fire alarms

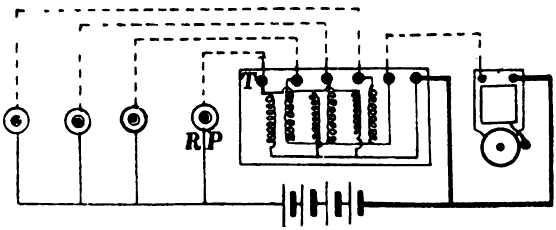


Fig. 72. Circuit Diagram.

should always be in circuit. In large houses it is well to have an indicator connected with the alarms, to show at once from which part of the house the signal has been given.

The connections of a 3-no. electrical replacement indicator are shown in Fig. 72. When the replacing push *R P* is depressed, current is sent, *via* the terminal *T*, through the left hand or replacing coils of all the indicator movements, so sending back to their normal position any of the flags which happen to have been deflected. The student should again refer to Fig. 56 and its description. These indicators are useful where it is required to have the replacement done from a distance. Pendulum indicators are not always favoured,

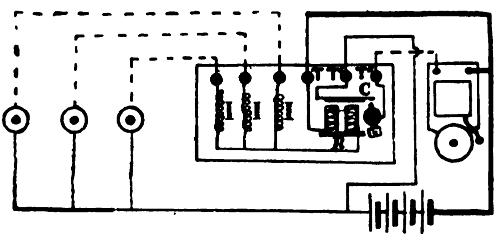


Fig. 73. Circuit Diagram.

as they are liable to stop swinging before the servant has had time to see which room has signalled. Mechanical replacement indicators necessitate one going up to it to replace the flags. With electrical replacement indicators, more than one replacing push may be used, and they may be placed at any distance from the indicator.

Fig. 73 shows the connections of a 3-no. mechanical or self-replacement relay indicator, and it should be studied in conjunction with Figs. 60 and 61. The current from either of the distant pushes, after passing through

an indicator coil I, traverses the coils of the relay R, and returns by terminal T to the − pole of the battery. The relay contact c is thus made, and current entering from the + pole of the battery by the terminal T', goes to the bell *via* T'', and so back to the battery.

Fig. 74 shows a magneto generator joined up with a magneto bell. (See also Figs. 63, 64, and 65.) Two or more generators or bells may be put in the same circuit, in series; in which case, when either of the generators is worked, all the bells will ring.

Electric bell work is immensely facilitated by an ability to work out circuit diagrams. Those illus-

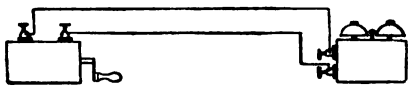


Fig. 74. Magneto Bell Circuit.

trated above show only the simpler kinds of circuits, but having mastered these, an intelligent student should be able to plan out almost any kind of ordinary circuit. [*See Exercises, pp.* 140 *and* 141.]

* 86. Winding and Connection of Electro-magnet Coils. The strength of an electro-magnet depends, roughly speaking, upon two things—the current, and the number of turns of wire on its coils. Thus a magnet wound with many turns of fine wire with a weak current passing through it, may pull its armature as strongly as a magnet wound with comparatively few turns of thick wire carrying a strong current.

Bells, indicator movements, and other instruments for long distance working, where the current is weakened by the resistance of the circuit, are wound with many turns of fine wire; while apparatus for short distance working have a comparatively short length of thick wire on their coils. Relays are wound with comparatively fine wire, as they are required to work with weak currents.

From what we have said above, it is clear that with a given current, the greater the number of turns of wire on the coils, the greater will be the pull of the magnet. Now if we have a certain bobbin filled with a certain number of turns of comparatively thick wire, it is evident that, in order to get a greater length and number of turns of wire on to the same sized bobbin, we must wind it with finer wire. There is a limit to the size of bobbins, and having fixed on this limit, we choose the largest possible size of wire which will fill the bobbin, and give the required number of turns. The finer the wire, the greater the resistance. We do not use fine wire because there is any particular virtue in it, but because it is necessary in order to get the requisite number of turns on the coil. These remarks apply to various apparatus, galvanometers for instance. It is a puzzle to some students that an instrument with high resistance should, generally speaking, be more sensitive to weak currents than one with a low resistance. The resistance is not there because it is wanted, but because it is the result of the use of a great length of fine wire. Ordinary bell and indicator

coils may be wound with No. 24 or 26 S.W.G. wire, finer sizes being used according as the desired number of turns is increased.

In some work it is necessary to lessen the inductance of a magnet: this may be done by joining its coils in parallel, instead of in series. When doing this, care must be taken to see that the current flows round the coils in opposite directions, so as to give the proper polarity.

CHAPTER V.—QUESTIONS.

In answering these questions, give sketches wherever possible.

N.B.—Circuit diagrams to be drawn according to the rule given in § 79.

*1. Describe the Leclanché cell, and add some hints as to how to maintain it in working order. [Prel. 1894.]

*2. Distinguish between the ordinary Leclanché, the agglomerate-block, the Lacombe-Leclanché, the Leclanché-Barbier, and dry cells.

*3. Say what you know about the E.M.F. and internal resistance of cells for electric bell work.

*4. Define the terms "in parallel," "in series," "on open circuit," and give sketches in illustration. [Prel. 1894.]

*5. What is the white metal used for the tips of the contacts in electric bells? Why is silver not used for this purpose? [Prel. 1895.]

*6. Sketch and describe the action of an ordinary trembling bell.

*7. Distinguish between the ordinary trembling, the single-stroke, and the continuous-ringing bell.

*8. Say what you know about pushes and pulls, and distinguish between such and a switch.

*9. Sketch and describe the fixing of some kind of burglar alarm.

*10. Distinguish between the different kinds of fire alarm, and describe any one pattern.

*11. Why are electric bells apt to work badly when coupled in series? [Prel. 1895.]

*12. Explain the application of Maycock's rule for electric-bell wiring, in circuit diagrams, and in actual work. In what ways does it facilitate work?

*13. How many kinds of electric indicator movements are there? Sketch and describe one of each kind.

*14. Sketch clearly and explain the internal arrangements of a 4-no. electrical replacement indicator, showing the replacing movement.

*15. Sketch the connections needful for bells between two places, *A* and *B*, so that a person at *B* can ring the bell at *A*, and that a person at *A* can ring the bell at *B*. One battery (of 2 or 3 cells) only to be used; and only one bell to ring at a time. [Prel. 1894.]

*16. Explain concisely the construction and use of relays.

*17. Give a diagrammatic sketch of a continuous-ringing bell, and show how you would connect it up with 6 burglar alarms.

*18. There is an electric bell at *A* and another at *B*, with a single line of wire between them. Show by sketches what arrangement of cells and switches is required that a person at either end can call up on the other bell without ringing that at his own end. [Prel. 1895.]

*19. Give a diagram showing how the armature of a magneto "generator" is connected with the coils of a magneto bell. Explain the action of the latter.

*20. Why is there a permanent steel magnet in the bells that are to be used with magneto-ringers? [Prel. 1894.]

*21. If electric bells are to be made to ring (by a magneto-ringer) through a line many miles in length, why must fine wire be used, both in the coils of the ringer and in the coils of the electro-magnet in the bell? [Prel. 1894.]

*22. Give a diagram with connections of a relay working an electric bell. [Prel. 1895.]

*23. Give a diagram representing an eight-roomed house fitted up with electric bells, burglar and fire-alarms. Give the names and positions (ground floor, first floor, etc.) of the rooms, and also show the positions of the various bells, indicators, batteries, etc., used. It is not necessary to show the actual position of the pushes and other contacts, only the rooms they are in.

*24. Show the internal and external connections of a 6-no. electrical replacement relay indicator, with 3 replacing pushes.

*25. How can you convert a bar of iron into a magnet? If you have a small electromotive force, and no appreciable resistance in the rest of the circuit, would you use thin wires, or thick, for winding an electro-magnet? [Prel. 1894.]

*26. Referring to Fig. 67, supposing it was desired that a bell at a place half-way along the line should ring every time *B* signalled to *A*, but not when *A* signalled to *B*: how would you arrange this without disturbing the connections at either *A* or *B*?

*27. One bell, one battery, and four pushes are to be so arranged that one of the pushes rings the bell "single stroke," while the other three pushes ring it "trembling." Sketch the circuit, and say if you think the arrangement would work well.

*28. Two bells *A* and *B*, one battery, three pushes, and a two-way switch, are to be so arranged that one push rings bell *A*, another push bell *B*, and the third push either bell according to the position of the switch. Sketch circuit.

*29. A mansion is fitted with fire alarms on each of 3 floors, as well as the ground floor and basement; and with burglar alarms on the basement, ground, and first floors. The fire-alarms work through an indicator and 3 bells in different parts of the premises, while the burglar alarms actuate a separate indicator and one bell. The indicators show from which floor the alarm is given. Give a sketch of the connections, showing, for simplicity, only 2 alarms of either kind on each floor.

*30. Modify Fig. 66 to represent three pushes in one room working one indicator movement, two pushes in another room working the second movement, one push in a third room working the third movement, and a seventh push working the bell only. Under what circumstances would such an arrangement be useful, do you think?

*31. There are three places, *A*, *B*, and *C*. At *A* is a push which, working through the left-hand contact of a two-way switch, actuates a continuous

ringing bell at *B*, using E. return and a battery of 3 cells at *B*. When switch lever is on right-hand contact, the bell at *B* is actuated as before, but the current passes through a relay which closes the circuit of a continuous ringing bell and 4 cells at *C*, using E. return. Sketch circuit.

*32. A house consisting of 7 rooms: hall, dining-room, and kitchen (ground floor); drawing-room and 1st bedroom (1st floor); 2nd and 3rd bedrooms (2nd floor); is to be fitted up as follows. A 6-no. indicator and bell in kitchen are to work from all the other rooms; pushes in hall, dining-room, and 1st bedroom work 3-no. indicator and bell in 3rd bedroom. A burglar alarm and fire alarm each in kitchen, hall, dining-room, and drawing-room, work 2-no. indicator and bell in 1st bedroom. Fire alarms work one no. of indicator, the burglar alarms work the other no. One battery of 6 cells, situated in kitchen, is to furnish all the current. Sketch skeleton of house, and then draw circuit.

33. Explain clearly, by the help of what you read in Chap. IV., why joining the coils of an electro-magnet in parallel lessens its inductance.

*34. Define the following terms: resistance, alloy, amalgam, polarisation, E.M.F., one ampere, one ohm, one megohm, one volt, one kilowatt. [Prel. 1896.]

*35. Show how to join up two electric bells by a single line and an earth return, so that a person at either end can ring up at the other end without ringing his own bell. [Prel. 1896.]

*36. Name the chief kinds of batteries used for electric bells and for telegraphy, and the materials used in them. [Prel. 1896.]

*37. Why do sparks occur in ordinary electric trembling bells? How can they be prevented or reduced? [Prel. 1896.]

*38. Under what circumstances would you select as an electromagnet (*a*) one wound with many turns of very fine wire; (*b*) one wound with few turns of thick wire; (*c*) one having its core made up of a number of stampings of sheet iron? [Prel. 1896.]

*39. Describe the construction of a Leclanché cell, and state what are its advantages and disadvantages. Under what circumstances would you employ Leclanché cells? [Prel. 1897.]

*40. Describe, with sketches, a single-stroke bell, and a trembling bell. [Prel. 1897.]

*41. What is your opinion regarding the ordinary method of stapling electric bell and telephone wires to walls? [Prel. 1897.]

*42. Describe an electric fire alarm in detail, with sketches. [Prel. 1897.]

*43. Define the terms: insulation, insulator, battery, switch, condenser, electromotive force, relay, depolarizer, vacuum-tube, electrode. [Prel. 1895.]

*44. Describe three different types of primary batteries, and state what kind of work each type is most suitable for. [Prel. 1898.]

*45. Describe, with sketches, a magneto-generator, such as is used for telephone calls. [Prel. 1898.]

N.B.—Circuit diagrams to be drawn according to the rule given in § 79.

CHAPTER VI

The figures refer to the numbered paragraphs.

* 87. INTRODUCTION. In this chapter we shall investigate the properties of the magnetic circuit, the relations of the various magnetic quantities to one another, and magnetic measurements. The whole subject is one which presents many difficulties to the student, but these will be overcome by careful and repeated reading.

* 88. MAGNETIC PROPERTIES OF MATERIALS. Iron and steel are the metals whose magnetic properties are of most practical value. When we say that a piece of iron or steel is magnetised, we mean that its already magnetised particles have been so arranged in line as to give us useful magnetism. The following experiment illustrates the different free magnetic properties of various samples of iron and steel. The difference

between *free* and *useful magnetism* will be explained in the next paragraph.

Experiment.—Apparatus required:—3-cell battery, coil of wire, heap of tacks, and 4 rods about 6″ long and ½″ dia., respectively of soft annealed iron, cast iron, soft steel, and hardened steel.

At first neither of the rods should show any free magnetism when dipped into the tacks.

Now insert each rod in turn within the coil, give it a few taps with a hammer, and observe the number of tacks which each will pick up.

Tested in this way, it will be found that their order of goodness is as follows:—

1. Soft iron.
2. Soft steel.
3. Cast iron.
4. Hard Steel.

Now, after withdrawing them from the coil and giving them one or two taps with the hammer, again test each bar, and it will be found that, as regards the free magnetism exhibited, the above order is reversed, as follows:—

1. Hard Steel.
2. Cast iron.
3. Soft steel.
4. Soft iron.

The hard steel will pick up the most tacks, though not quite so many as it did when within the coil, while the soft iron will probably not pick one up.

* 89. Remanence or Residual Magnetism. The free magnetism left in a bar of iron or steel after it has been removed from the influence of a current-carrying coil or other magnetising agent, is sometimes spoken of as *remanence* or *residual magnetism;* and the property in virtue of which this magnetism is retained is known as *retentiveness* or *permanency.* Thus the retentiveness of cast iron is greater than that of soft iron, but less than that of hard steel.

Theoretically, it is because of the supposed closeness with which the molecules of hardened steel are packed together, that it is enabled to retain its free magnetism; and it is because of this also that the steel was not so strongly magnetised as the soft iron while within the coil. (*See Exp. in preceding* §.) The molecules of the latter may be supposed to be able to move among themselves with great freedom; so that when within the coil, the majority of the molecules turn in line in obedience to the lines of force of the coil; and when removed from the latter's influence, they turn so as to complete their magnetic circuits among themselves, and so give out no free magnetism.

Free magnetism exists where magnetic lines have to pass through air in order to complete their circuits. There is no free magnetism in a uniformly magnetised ring of iron, or in an ordinary transformer core, but there is *useful magnetism.* Although most people accept the molecular theory of magnetism, the practical way of accounting for the increased number of lines when a magnetisable body is placed in a magnetic field, is to say that it is in virtue of the superior *magnetic conductance* of the magnetisable body, as compared with air or other so-called non-magnetisable body. The term for magnetic conductance is *permeance*, though *permeability* is often incorrectly used in this sense. (§ 95A.)

90. THE MAGNETIC CIRCUIT. Ohm proved experimentally that the ratio of E.M.F. to current in a circuit of perfect sameness as regards the material of the conductor, maintained at a constant temperature, and not

containing any other E.M.F. but the one considered, was constant.

Expressed in symbols this is:—

$$R = E \div C.$$

This ratio was given the name *resistance*, and has since come to be looked upon as a property of the conductor, as indeed it is, varying with its dimensions and kind, and to a slight extent with its temperature (§§ 24, 26). Of late years, the apparent similarity which exists between the electric and magnetic circuits has been pointed out, and attempts have been made to treat the relationship between the *magnetic force* (H) producing a *magnetic flux* (or flow of lines), and the *flux density* (or intensity of the magnetic field) in the metal (B); in a very similar way to that in which E.M.F. and current are treated in Ohm's law,

i.e., $$\mathsf{R}' = \mathsf{H} \div \mathsf{B},$$

R' representing the *magnetic resistance* offered by the metal (§ 95A). Such a law of the magnetic circuit, similar to Ohm's law, is useful for beginners, to give them a preliminary idea; but, as will be pointed out later on, it is only approximately true.

If we take a magnet in air, we find that the magnetic properties of the magnet affect the surrounding space, and we call the space a magnetic field. The simplest way to detect the direction of this field, is to bring within its influence a small delicately suspended or pivoted magnetic needle. The position in which the needle sets itself at any point, indicates the

direction of the field at that point, the N. pole of the needle pointing in the + direction along the lines. To measure the intensity or strength of the field, *i.e.*, the closeness with which the lines are packed together, we might find the force exerted on one pole of a very long thin magnet, the length being so great that the other pole was practically beyond the influence of the field. Such a single pole, if free to move, would travel along the field, the pull or push exerted on it depending on the intensity of the field.

Permanent magnets are but little used in electrical engineering work, and the laws governing the forces and actions of such magnets upon one another, have to be considerably modified before they can be applied to electro-magnets.

Lines of force in air tend to produce *lines of induction* (induced magnetism) in any mass of metal to which they have access. The term *lines of force* is in practice used to denote magnetic lines in air; where the latter pass through metal they are called *lines of induction.* The reason for this is, that the number of magnetic lines passing through a portion of metal forming part of their circuit, may be greater or less than the number which would pass were the same space occupied by air only, according as the metal is *paramagnetic* or *diamagnetic.*

Paramagnetic bodies (iron, steel, nickel, cobalt, manganese, chromium, cerium, titanium, and platinum (?), and their ores and salts,) are those which "conduct" lines of force better than air. All other

bodies are *diamagnetic*, *i.e.* they have less magnetic conductance than air. Paramagnetic bodies are sometimes called *magnetic bodies*, and diamagnetic bodies *non-magnetic*. The difference between magnetic and so-called non-magnetic bodies is, like that between conductors and insulators, one of degree only.

The magnetic circuit is not, in most cases, as clearly defined as the electric circuit through which electricity flows, for the simple reason that while we may confine electricity to any given path (generally a metal wire), by surrounding that path with something which, practically speaking, will not allow electricity to flow through it, viz., a good insulator: there is no such thing as a magnetic insulator, for all bodies and gases conduct magnetic lines to an appreciable degree.

Though there is no such thing as a magnetic insulator, yet an instrument, such as a galvanometer, may be screened from external magnetic forces by enclosing it in a massive soft iron case. (*Example*, Thomson's [Lord Kelvin's] marine galvanometer.) Similarly, a magnet placed in a thick, soft iron box would not affect a magnetic needle outside the box. Such cases are analogous to short-circuiting the terminals of an instrument, or dynamo, or battery, by a thick conductor; whereon there is little or no inducement for electricity to flow by any other path.

Lines of force have no ends, and may be looked upon as stretched elastic bands which are always endeavouring to shorten themselves or shrink up. In diagrams it is not always necessary to show their

complete path, as it would generally take up too much room, even were it possible to say exactly where a magnetic field ended.

The electric and magnetic circuits, however irregular in shape they may sometimes be, are always linked together. Thus in Figs. 9 and 17 the magnetic circuit, which is wholly through air, encircles the electric circuit. In Fig. 19 one half of the magnetic circuit is

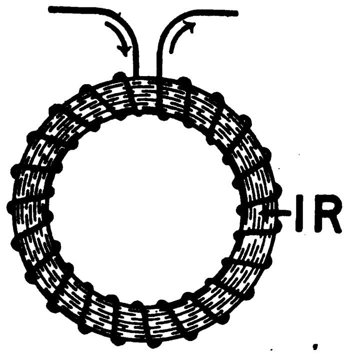


Fig. 75. Magnetised Iron Ring.

of iron, and the other of air. In Fig. 17 the circuit followed by the lines is through the coil and back again on all sides. In Fig. 18, iron is introduced into the principal part of the circuit, and its effect of drawing the lines together by reason of its better permeance (magnetic conductance), is clearly shown. In Fig. 20, although we should get poles at the two ends of the spiral, as shown, the lines would not wholly follow the spiral iron path, but would leak across at

the beginning and end of each separate turn, and there would consequently be weak poles there also.

For further consideration, let us take as example a ring of iron (Fig. 75), round which a coil of wire has been wound, and send a current through the coil. Then we have two closed circuits, the electric and the magnetic.[1] If we consider the first, we have by Ohm's law, $C = E \div R$. In a similar manner we may roughly talk about the *magneto-motive force*[2] (which is proportional to the current, and to the number of turns of wire on the coil [§ 92],) giving rise to magnetic lines in the magnetic circuit, in this case composed of the iron ring; the *flux* or total number of lines set up; and the *reluctance* or *magnetic resistance* opposed by the ring to the setting up of these lines.

Thus:—

(Electric Circuit.)

$$\text{Current} = \frac{\text{Electro-motive force.}}{\text{Resistance.}}$$

(Magnetic Circuit.)

$$\underset{\text{(Magnetic current).}}{\text{Flux}} = \frac{\text{Magneto-motive force.}}{\underset{\text{(Magnetic resistance).}}{\text{Reluctance}}}$$

[1] An electric circuit must of necessity be "closed" to allow electricity to flow. By *closed magnetic circuit* is meant one in which there is a complete iron path. In a magnetic circuit the lines will "flow" whether the circuit is "opened" or "closed."

[2] *Magneto-motive force* must not be confused with *magnetic force.* With a given current, the former is proportional simply to the number of turns on the coil, while the latter depends on the turns and the length of the coil. (§§ 92, 95A, 96.)

Unfortunately, as we have before stated, the above simple law as applied to the magnetic circuit does not admit of general application. Resistance is a quantity independent of the current flowing through a conductor, provided the latter is kept at a constant temperature; whereas the reluctance or magnetic resistance of the iron ring will vary with every change in the number of lines of induction passing through it.

In Fig. 75, the iron ring *I R* is entirely wound round

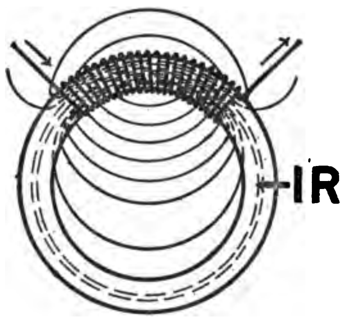


Fig. 76. Magnetised Iron Ring.

with the coil of wire, and the lines, which are primarily due to the current in the coil, will keep wholly to the iron path, and there will be no magnetic leakage. If, as in Fig. 76, the current-carrying wire is all wound on one small portion of the iron ring, there will be considerable leakage of lines through the air, the amount of which will depend upon the ampere-turns of the coil, and the size and cross section of the iron ring. The thicker the iron ring is, the more inducement will

there be for the lines to follow the iron path. The iron ring has much more magnetic conductance or permeance than the surrounding air, but its permeance will decrease, and its reluctance (magnetic resistance) increase, as the number of lines passing through it increases.

The number of lines of induction passing through unit area (sq. cm.) of the material forming the magnetic circuit, is called the ***induction***, and is denoted by the symbol B. B is variously called :—

The Induction;
The Magnetic Induction;
The Internal Magnetisation;
The Intensity of the Induction;
The Permeation;
The number of lines (or lines of induction) in the material per sq. cm. of cross-section;
The Flux-density;

all these terms meaning the same thing. The first-named is the one most commonly used, and we therefore mostly use it here; but it is badly chosen, as it is employed in various other senses also. The last-named term (flux-density) is good, and should gradually displace the others. The methods by which this quantity B can be measured, will be dealt with later on.

91. The Magnetic Circuit (*continued*). In the preceding paragraph a general idea of the magnetic circuit was given: we will now proceed with the subject in a more precise manner.

If an electric conducting circuit is taken, and there is an electro-motive force in it, there will be a current whose value is found by dividing the electro-motive force by the resistance of the whole circuit. If a ring-shaped core of iron is wound with wire, and a current is maintained in the wire, the iron of the ring will be magnetised (Fig. 75). The magnetic excitation produced by the coils of wire may be compared with the E.M.F. of the electric circuit, and is sometimes called the *magneto-motive force* (see footnote, p. 149); and the "magnetic current," or total *magnetic flux* (or flow of magnetic lines), would be found by dividing the magneto-motive force by the *magnetic resistance* or *reluctance* of the iron ring. A difficulty arises, however, for as regards electric current, bodies can be divided practically into conductors and non-conductors: but in the magnetic circuit, even so-called non-magnetic bodies (§ 90), such as air, will carry the magnetic flux; so that a coil of wire with a current produces lines of force even if there is no iron (Fig. 17). The result is that the magnetic circuit is not well defined. In the iron ring most of it is through the iron; but, especially if the exciting coil is all wound in one place, there is *magnetic leakage* through the air too (Fig. 76). If our electric circuits were all so leaky that we never knew the whole current produced by the E.M.F., and also never knew the resistance of the circuit (as would be the case, for example, if a hermetically sealed battery and a naked copper circuit were immersed in mercury), we should be unable to deal

with the current. We might define the current as the current in the copper only, but even that would be greater near the battery than in the more remote parts of the circuit. Again, in such a case, the current in the copper could not be found by dividing the E.M.F. by the resistance of the copper only; for Ohm's law could not very well be applied in a case where there was a leaking round of electricity by other paths, as through the mercury.

The magnetic resistance method of dealing with the subject is thus of little value when numerical calculations have to be made; but it is very useful in giving students, who have mastered Ohm's law, a preliminary idea of the phenomena of magnetism.

92. THE MAGNETIC CIRCUIT (*continued*). A more complete and satisfactory theory, which is unfortunately much more difficult to understand at first, requires us to regard a current-carrying coil of wire as producing a *magnetic potential* or *pressure* tending to set up magnetic lines.

Magnetic potential is measured by the work that would be done on a unit pole, if such a thing could be got loose and allowed to move round the coil so that its path was linked with the coil, *i.e.*, so that it traversed the magnetic circuit. A C.G.S. *unit magnetic pole* is one that repels a similar unit pole, one centimetre distant, with a force of one dyne (§ 7). The C.G.S. *unit current* is the current which, if led near the unit pole through a bit of circuit one centimetre long and one cm. radius, so that the pole is at the centre,

acts on it with a force of one dyne. Suppose instead of a bit of circuit we have a complete current turn, the force will then be 2π dynes. For if unit current exerts a force of one dyne when traversing a part of a circle equal in length to the radius, as just stated; the same current will exert a force of 2π dynes if it makes one complete turn round the magnet pole, for the circumference of a circle is 2π times the length of its radius (§ 24).

The intensity or strength of a magnetic field at any point, is measured by the force it will exert on a unit magnetic pole. A *field of unit intensity* or strength will act on a unit pole with unit force (one dyne). It is convenient to imagine that in a field of unit strength there is one line of force for every square cm. unit of area; so that a field of any strength n is one having n lines of force per square cm., n being the particular number of lines in question. Lines of force calculated according to this method are called *C.G.S. lines.*

As a unit pole is one which acts on a similar pole with unit force at unit distance, it follows, from what we have just said about unit field, that there is unit strength of field at unit distance from such a pole. Now take any point to represent our unit pole, and suppose it surrounded by an imaginary sphere of unit radius, then the surface of the sphere will at all parts be at unit distance from the pole, and the strength of the field will be unity everywhere on the surface of this sphere. But unit field has one line of force for every square cm. of area; it consequently

follows that there are 4π *lines of force proceeding from a unit pole*, for the surface of a sphere is $4\pi r^2$, where r is the radius: and the square of 1 is 1.

It can be proved, without any advanced mathematics, that if a unit pole is allowed to travel round any path linked with a unit current making one turn, as referred to above, the work done will be 4π ergs. This is true whether the interlinked path be air, or metal, or both; and whatever shape or size the wire coil is, provided it has one current turn. The magnetic potential of an electric circuit or coil is thus 4π times the current turns. As we are now working in the C.G.S. system, and the C.G.S. unit of current is ten times the ampere, the magnetic potential (in ergs per unit pole), or the magneto-motive force, is $0{\cdot}4\,\pi$ times the ampere-turns in the coil, *i.e.* 1·257 times the ampere-turns.

Magneto-motive force (M.M.F.).
$= 4\pi\,CN = 12{\cdot}57\,CN$ when C (current) is in C.G.S. units,
or $= {\cdot}4\,\pi\,CN = 1{\cdot}257\,CN$ when C is in amperes,
N being in each case the number of turns.

Generally we understand C to mean current in amperes.

The idea of magnetic potential is difficult to grasp; but it is analogous to electric potential, or pressure in hydraulics. The pressure in a hydraulic circuit, for instance, can be found by finding the work done when a unit volume of water goes round the whole circuit,

arriving eventually at the same position. In hydraulics we deal not only with pressure, but if the pressure is high in one place and low in another, owing to power being used up between the points, we can say how much the pressure falls per foot of pipe. Similarly in electric circuits the potential falls gradually, and we can say there is a loss of so many volts per yard in a conductor with a current. Again, in magnetic work we can think of fall of potential. The unit pole would do so much work per centimetre in one place, and so much per centimetre in another; the amount being determined by the force acting on it, as work is numerically equal to the force multiplied by the distance (§ 8). The force which would act on a unit pole at any point is called the *magnetic force* at that point, and the magnetic force is spoken of whether there is a pole there to be acted on or not. The magnetic force is thus equal to the rate per centimetre at which the magnetic potential falls. Magnetic force is also called *magnetising force*, and is commonly denoted by the block letter H. As we have before explained, any field where there is force may be represented by filling it with lines, such that the number of lines of force per sq. cm. is the same as the number of dynes that would be exerted on a unit pole inserted there. These lines of force are a very useful convention. *Magnetising* or (as we prefer to call it) *magnetic force* (H) *may therefore be practically defined as the number of lines per sq. cm. in air at any part of the magnetic circuit.*

In an electric circuit, take one point, in the interior of a copper bar for example. Imagine a centimetre cube cut so that the electricity flows in and out at opposite sides, but does not cross the other four sides at all. The current would be found by dividing the difference of potential between the opposite faces by the resistance of the cube of copper; or by multiplying the P.D. by its conductance, for conductance is the reciprocal of resistance. That is to say, the current in the cube is equal to the product of the fall of potential per centimetre, and the specific conductance of the copper. The current per square centimetre of cross section is the current density. The current density in a conductor is thus found by multiplying the specific conductance of the material, by the rate of fall of potential at that point. Similarly, in the magnetic circuit, the flux-density or number of lines per □ cm. is equal to the rate of fall of magnetic potential (or the magnetic force,) multiplied by the *specific magnetic conductance* of the medium.

This quantity, the specific magnetic conductance, must be equal to the reciprocal of the specific magnetic resistance or specific reluctance or *reluctivity* (R), just as in the electric circuit specific conductance (or conductivity) is the reciprocal of specific resistance (or resistivity). Magnetic conductance is called permeance, while specific magnetic conductance is called *permeability*, and is denoted by the Greek letter μ (mu).

From § 90:—

$$\mu = \frac{1}{R} \text{ just as conductivity} = \frac{1}{\text{resistivity}};$$

i.e., as ohms per c.c. $= \dfrac{1}{\text{ohms per c.c.}}$ in the electric circuit. (§ 21.)

Whichever method of regarding the theory of magnetic propagation in metals be considered, we find that the four quantities, magneto-motive force or magnetic potential (1·257 ampere-turns): magnetic force (H): induction or flux-density (B): and permeability (μ) are required. These will now be discussed more in detail.

93. CURVES. A "*curve*" may be defined as a diagram in which a *curved or straight* line is employed to represent the relation of certain varying values to each other. Thus a curve may show the relation between the deflections of a galvanometer and the currents producing them: or between the magnetic force acting in a coil of wire and the induction (*i.e.*, number of lines per square cm.) in a piece of iron: or between the E.M.F. and the current developed by a dynamo driven at a constant speed, when the external circuit resistance is altered: etc., etc. A special kind of paper, called *squared paper*, is employed for setting or "plotting" these curves on: the paper being divided into small squares by equidistant horizontal and vertical lines. (Fig. 77.) Distances measured along the horizontal line OX are called *abscissæ*, and those measured along the vertical line OY, *ordinates*. The method of obtaining the curves will be explained in each particular case under notice.

94. Curves of Magnetisation or Induction. In Fig. 78 is shown a set of ***curves of magnetisation or induction*** of different samples of iron and steel, in which the abscissæ represent the different values of the mag-

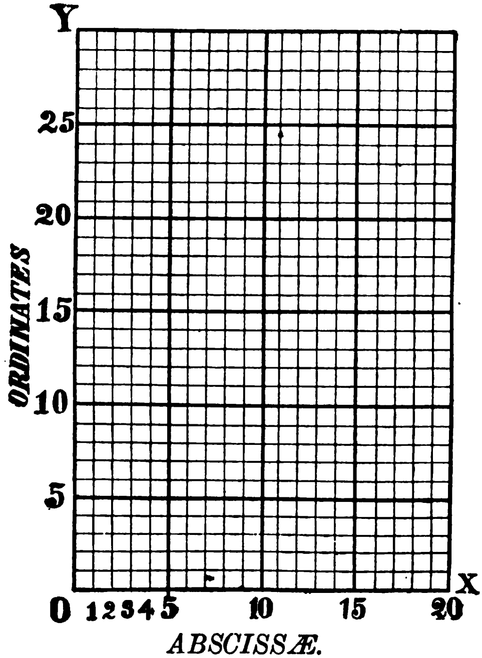


Fig. 77. Squared paper.

netising or magnetic force (H), and the ordinates the resulting induction (B). These curves are due to the researches of Prof. Ewing, and refer to samples of soft iron, hardened iron, cast iron, annealed steel, hard drawn

steel, and glass-hard steel, *i.e.*, steel which has been hardened but not tempered. It will be noticed that these results bear out what was said in §§ 88 and 89. Before being tested, each sample was perfectly devoid of free magnetism. Under a magnetising force of 2·5, the annealed iron gave a value for B of about 8,000, the cast iron about 3,000, the hard iron 1,000, while with the three samples of steel the induction was practically nil. When $H = 5$ we have the following approximate values:—

Soft iron, 11,000.
Cast iron, 4,000.
Hard iron, 2,150.
Annealed steel, 900.
Hard steel, 800.
Glass-hard steel, 600.

Notice that this small magnetising force is sufficient to give nearly the maximum induction in soft iron, while there is only about one-fifth the induction in hard iron. This points to the importance of using well annealed iron of the best quality whenever possible. It will also be seen that though much less even than that in hard iron, the induction in annealed steel is more than that in the hard-drawn steel, and still more than that in the glass-hard steel. At these low values of H, however, there is little appreciable difference in the values of B for the different samples of steel. When $H = 10$, it will be noticed that the curve for annealed iron is turning round in a horizontal direc-

tion. This denotes that we have nearly reached the practical limits of induction, or in other words, that the iron is becoming ***saturated.*** This being so, any further increase in the magnetising force increases the induction very slightly indeed. The hard iron, however, does not begin to become saturated until

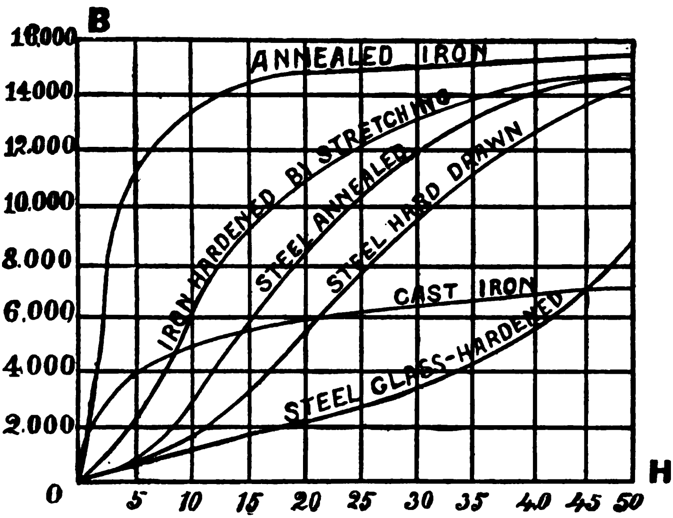


Fig. 78. Curves of Induction.

about three times the magnetising force has been applied, that is, when H = 30; and even at this point on its curve it only exhibits the same induction as would be given by soft iron with H as low as 9. Roughly speaking, this means that a magnet constructed of bad unannealed iron would require 3½

times as many ampere-turns to magnetise it to a given induction, as would a similar sized magnet of good annealed iron.

When $H = 50$, it will be noticed that both the annealed steel and the hard steel have practically reached the saturation point, while the glass-hard steel curve is still rising sharply. From the position of this latter curve, the student will understand how difficult it is to magnetise very hard steel, except with a great magnetising force. Thus with H at 10, we see that the soft iron has practically reached its maximum value, while the steel is only just getting magnetised. The induction in glass-hard steel when $H = 50$, is equivalent to the induction in soft iron when $H = 2{\cdot}5$: that is to say, hard steel requires about 20 times as many ampere-turns to magnetise to a given induction as soft iron. It need hardly be pointed out how important to the engineer is a knowledge of the properties of the magnetic substances, to which we have just briefly referred.

95. Magnetic Qualities of Iron. The permeability or specific magnetic conductance of iron, unless very strongly magnetised, is much greater than that of any other body. It is therefore generally used as much as possible to constitute the magnetic circuit. In a dynamo, for instance, about 80% of the magnetic potential (or pressure setting up the lines,) due to the exciting coils, is devoted to the air spaces between the pole faces and the armature core. Thus, if a dynamo has 10,000 ampere-turns, and air spaces of 1 cm.; the

magnetic potential is $1{\cdot}257 \times 10{,}000$, or about 12,600 ergs per unit pole; 80% of this, or say 10,000 ergs, being used up in the air spaces, *i.e.* 5,000 for each air space. As the permeability of air is, by definition, equal to 1, we have thus an induction of 5,000 lines per sq. cm. in the air spaces.

As was mentioned in § 92, *reluctance* or *magnetic resistance* is the reciprocal of *permeance* or *magnetic conductance*; and *reluctivity* or *specific magnetic resistance* is the reciprocal of *permeability* or *specific magnetic conductance.* Thus the reluctivity of soft iron is very much less than that of hard steel, while on the other hand its permeability is greater.

The value of μ (*i.e.* permeability) varies of course with different samples; and with any particular piece of iron or steel, first increases and then decreases as the magnetising force (H) increases. The reason of this is as follows. The induction (B) in a piece of iron is a consequence of the alignment of its magnetised molecules; and as the magnetising force is increased, more and more molecules are set in line, until there remain comparatively few to be acted upon. In this state we have what is known as the *saturation* of iron. As, consequently, the induction (B) cannot go on increasing at the same rate as the magnetising force (H), it follows that the ratio $\frac{B}{H}$, *i.e.* the permeability (μ), must get less and less as the magnetising force is increased. The permeability of any particular sample of iron or steel is therefore not a

constant quantity, but diminishes as the metal becomes saturated. The permeability of air is taken as unity, so that in air $B = H$.

As
$$\mu = \frac{B}{H}, \quad B = \mu H.$$

Thus in soft iron, when B is 12,000 and $H = 6{\cdot}5$ (see Fig. 78), the permeability is 1,846, for :—

$$\frac{B}{H} = \frac{12{,}000}{6{\cdot}5} = 1{,}846 = \mu.$$

If B is 1,500 and $H = 25$, the permeability is 60, for :—

$$\frac{B}{H} = \frac{1{,}500}{25} = 60 = \mu.$$

Practical limits of flux-density, induction, or B.

Wrought iron	16,000	lines	per	□ cm.
or	100,000	"	"	□ inch.
Cast iron	12,000	"	"	□ cm.
or	70,000	"	"	□ inch.

95A. SUMMARY OF TERMS. There is a confusing multiplicity of magnetic terms, and it may be well at this stage to summarise those which have already been mentioned.

Magnetism means the existence of lines of force. If these lines complete their path wholly through a magnetic medium, we may have *useful magnetism*, but not *free magnetism*: where they pass through air we have *free magnetism*.

Magnetic lines in air are called *lines of force*; in magnetic metal, *lines of induction*.

Paramagnetic or *magnetic bodies: dia-magnetic or* (so called) *non-magnetic bodies.*

Permeance or *magnetic conductance. Permeability* or *specific magnetic conductance* (μ).

Reluctance or *magnetic resistance* (R'). *Reluctivity* or *specific magnetic resistance* (R).

Remanence or *residual magnetism.*

Retentivity, or *permanency*, or *coercive force.*

Magneto-motive force, or pressure tending to set up magnetic lines, or 1·257 *current-turns*, or 1·257 *ampere-turns.* (M.M.F.)

Magnetic force, or *magnetising force*, or *lines per unit area in air*, or *M.M.F. per unit-length of magnetising-coil* (H).[1]

Magnetic potential, work done on unit pole = 1·257 *C N ergs per unit pole.*

Flux, or *magnetic flux, or "flow" of magnetic lines*, or "*magnetic current*," (F).

Flux-density, or *induction*, or *magnetic induction*, or *internal magnetisation*, or *intensity of induction*, or *permeation*, or *number of lines per unit area in material*, or *lines of induction per sq. cm. of cross section* (B).

Some additional terms whose meanings have not yet been defined are *magnetic moment of magnet* (M), *intensity of magnetisation* (I), *susceptibility* (κ), *hysteresis*, and one or two others.

[1] Strictly speaking, lines per unit area in air are not the magnetic force, but the result of magnetic force acting on a medium of unit permeability (μ). The flux per unit area has then the same value as the measure of H, but the quantities are of different kinds.

96. MEASUREMENT OF H. To obtain the values from which curves of induction (Fig. 78) are drawn, it is necessary to measure the quantities which can be observed by the use of ordinary instruments. The simplest method of doing this is to wind a coil of insulated wire round the rod of iron to be tested, and send a current through the wire. The number of turns (N), the length of the coil in centimetres (l), and the current in amperes (C) being known, it can easily be proved that the magnetic force (H) at the centre of the coil will be :—

$$\mathsf{H} = \frac{4\pi N}{l} \times \frac{C}{10} = \frac{\text{M.M.F.}}{l} \quad (\S\ 92) \qquad \text{(I.)}$$

the current being divided by 10 to bring it to C.G.S. units.

As $$\frac{4\pi}{10} = \cdot 4 \times 3{\cdot}1416 = 1{\cdot}257$$

the above (I) may be more simply written :—

$$\mathsf{H} = \frac{1{\cdot}257\, CN}{l} \qquad \text{(II.)}$$

Or in words :—

$$\text{Magnetic force} = \frac{\text{Magnetic potential}}{\text{length}} = \frac{\text{M.M.F.}}{\text{length}}.$$

This is only approximately true unless the length (l) of the coil is at least 10 or 12 times greater than its diameter. H represents the number of lines of force per sq. cm. of cross section of the coil, away from its ends, if air alone be the medium through which the magnetic lines pass. The total number of lines will

be got by multiplying H by the cross sectional area in sq. cms.

Example. Calculate the magnetic field at the centre of a long bobbin of wire, consisting of 1,000 turns in one layer wound on a tube 2 metres long and 4 cms. in dia., traversed by 10 amperes. How many lines of force are embraced by the centre of this solenoid?

By formula (II.) above:—

$$\mathsf{H} = \frac{1{\cdot}257 \times 10 \times 1000}{2 \times 100}$$
$$= 1{\cdot}257 \times 50 = 62{\cdot}85 \text{ lines per sq. cm.}$$

The flux (F) or total flow of lines in air will clearly be:—

$$\mathsf{F} = \mathsf{H} \times s \qquad \text{(III.)}$$

where s is the cross sectional area in sq. cms.

As mentioned in § 24, the area of a circle $= \pi r^2$, r being its radius; consequently the cross sectional area s of the solenoid of diameter 4 cms. is:—

$$s = \pi r^2$$
$$= 3{\cdot}1416 \times 4$$
$$= 12{\cdot}5664 \text{ sq. cm.}$$
$$\therefore \ \mathsf{F} = 62{\cdot}85 \times 12{\cdot}5664$$
$$= 790 \text{ lines embraced by centre of solenoid.}$$

In the above example, if iron were present instead of air, the number of lines would be greatly increased, as iron is a better medium for magnetic induction than air. The permeability of air is unity, while that of

iron reaches much higher values, depending upon the kind of iron used, and on the magnetising force employed (Fig. 78 and § 95).

If H for a current-carrying coil be as above, and we insert an iron core whose permeability $(\mu) = 100$ for that value of H, then the lines of induction per sq. cm. (*i.e.* B) would be equal to the permeability multiplied by the magnetic force, or

$$\mathsf{B} = \mathsf{H}\,\mu \qquad \text{(IV.)}$$

i.e.

$$\begin{aligned}\mathsf{B} &= 62{\cdot}85 \times 100 \\ &= 6285 \text{ lines.}\end{aligned}$$

The total flux (F) in the iron would then be

$$\begin{aligned}\mathsf{F} &= \mathsf{B} \times s \qquad \text{(V.)} \\ &= 6285 \times 12{\cdot}56 \\ &= 78939 \text{ lines.}\end{aligned}$$

97. Measurement of M, I, B and μ. H is obtained by calculation in the simple manner above described, but there is no *direct* method of obtaining B or μ. Of course if H and either B or μ be known, the other quantity is readily found, for $\mathsf{B} = \mathsf{H}\,\mu$. The value of μ is what is most often required in the workshop, in selecting iron for dynamos, transformers, etc.; and must be obtained by experiment. The loss by *hysteresis* (§ 100) is an important quantity in determining the most suitable grade of iron for parts subjected to constant reversals of magnetisation.

There are two methods by which B can be found: the first depends upon the relationship between B and

other quantities directly obtainable by a magnetic needle: and the second upon the quantity of an induced current which flows round a secondary coil wound on the sample of iron, when the current in the primary or magnetising coil is altered or reversed (§ 103). We shall only deal fully with the first method.

The *magnetic moment of a magnet* (M) is the strength of one pole × the distance between the poles; thus the *moment* (M) of the electro-magnet formed by the test piece and its magnetising coil is equal to the strength of either pole (m) of the magnet multiplied by the straight distance (l) between the poles, or

$$\mathsf{M} = ml. \qquad \text{(VI.)}$$

The *magnetic moment* or *moment* of a magnet is a measure of its tendency to turn when placed at right angles with the lines of any magnetic field.

M is readily compared with the *horizontal component of the Earth's magnetic force* (H), which varies at different parts of the Earth. Its value, which may be obtained from tables, is about ·18 dynes in London at present. Or we may compare M with that of another magnet or solenoid whose value has already been determined.

Taking the first case. A magnetic needle *n s* (Fig. 79) set in the Earth's field may be deflected by *TP*, the test piece of iron in the coil, which is placed with the line joining its poles at right angles to the magnetic meridian. Then if H = Earth's horizontal force, *d* the distance between centre of needle and either end

of test piece, and A the angle through which the needle turns:—

$$\mathsf{M} = d^3 \text{ H tan A.} \qquad \text{(VII.)}$$

(Tangent values of angles may be found from the table given in § 104.)

In Fig. 79, *N S* is a *deflection magnetometer*, *i.e.*, a

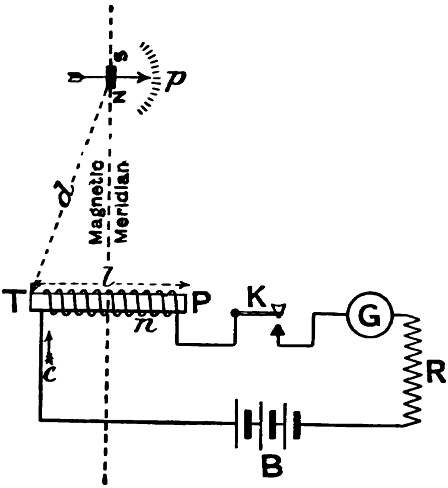


Fig. 79. Measurement of Magnetic Moment.

small and delicately suspended magnetic needle provided with a long pointer *p*, by means of which the amount of its deflection may be accurately noted. *TP* is the test piece of length *l*, put into the coil of *N* turns. *B* is a battery, *R* an adjustable resistance, *G* a galvanometer, and *K* a key. *TP* must be placed at

right angles with the needle's position of rest, *i.e.*, at right angles with the magnetic meridian.

The ***intensity of magnetisation*** (I) of a magnet or iron bar, is found by dividing the moment (M) by the volume (V) of the iron.

$$
\begin{aligned}
V &= \text{the length} \times \text{breadth} \times \text{thickness} \\
&= \text{,,} \quad \text{,,} \quad (l) \times \text{sectional area } (s) \\
&= l\,s.
\end{aligned}
$$

Then:—

$$I = \frac{M}{V} = \frac{m \times l}{l \times s} = \frac{m}{s} \qquad \text{(VIII.)}$$

In other words I is equal to the moment per unit volume $\left(\frac{M}{V}\right)$, or to the pole strength per sq. cm. $\left(\frac{m}{s}\right)$.

V (volume) can be ascertained by simple calculation from measurements with an accurate rule and calipers, and having got M and V as described, I is at once obtained (by VIII).

It can be proved that:—

$$B = 4\,\pi\, I + H \qquad \text{(IX.)}$$

and this is the relationship required in making tests of B and μ.

Calculation of μ. If we know the current in the coil (*C*) (Fig. 79), the number of turns (*N*), the length (*l*), the distance (*d*) between end of test piece (*TP*) and centre of needle, the angle of deflection of needle (A), and the volume of the test piece (V); then from IV., IX., VIII., and VII.:—

$$\mu = \frac{4\,\pi\,d^3\,H \tan A}{V\,H} + 1 \qquad \text{(X.)}$$

H being got from II. (§ 96). (See questions 32, 33, and 34, page 187.)

Example. A piece of wrought iron 20 cms. long by 0·8564 sq. cms. in area was placed within a coil of 157 turns. The length of the coil was 23·7 cms., and it could carry up to 10 amperes. At a distance of 29·53 cms., a deflection magnetometer was placed, the coil lying at right angles to the magnetic meridian (known as the

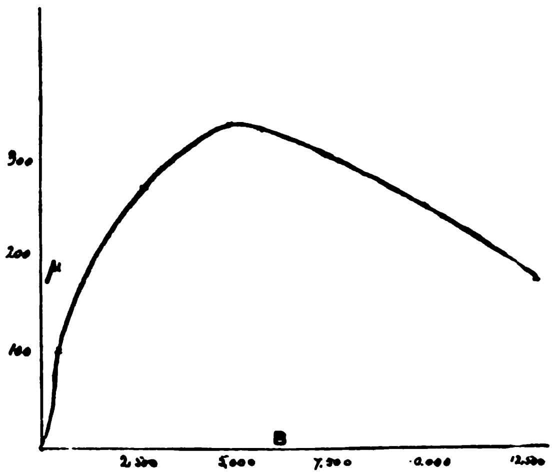


Fig. 80. Permeability Curve.

A position of Gauss). Currents varying from ·6 to 9·6 amperes were passed through the coil, the deflections of the magnetometer needle being noted.

The arrangement of apparatus was similar to that shown in Fig. 79, *G* being either a galvanometer or ammeter, and *B* any convenient source of E.M.F., such as a secondary battery or electric light mains.

The results obtained are plotted on the curve shown in Fig. 80. The values of μ, calculated from the experimental observations, were derived from formula X., in which the quantities V and H are found respectively by means of a rule and formula II. The values of μ were plotted as ordinates, and the corresponding values of B (calculated by formula IV.) as abscissæ. The result gives what is called a *permeability curve.*

98. Susceptibility. Another quantity concerning any magnetic material is its *susceptibility* (κ)[1] to magnetisation, which bears the same relationship to I that μ does to B.

Thus :—

$$\mathsf{B} = \mu \mathsf{H} \qquad \text{and } \mathsf{I} = \kappa \mathsf{H}$$

consequently :—

$$\mu = \frac{\mathsf{B}}{\mathsf{H}} \qquad \text{and } \kappa = \frac{\mathsf{I}}{\mathsf{H}} \qquad \text{(XI.)}$$

Susceptibility relates to the *intensity of magnetisation* produced in a body by a magnetising force, whereas permeability is a measure of its power of *conducting* lines. A full explanation of the former term involves the consideration of what is called *surface magnetism*, an idea which we wish to avoid if possible. Of the two quantities, permeability is, perhaps, the more important to the engineer, and this we have fully explained.

99. Cyclic and Periodic Curves. So far, we have only considered what happens when the iron (or other material subjected to a magnetic force) is magnetised

[1] κ = Greek letter, *kappa*.

by magnetic forces of varying value, but all acting in the same sense or direction. A more important case has, however, to be taken up at this stage; and that is, the effect of gradually varying the magnetic force, and also its direction. When a force or set of circumstances are caused to change from one value to another, finally returning to that from which a start was made, the operation is said to be a *cyclic* one. Thus a train on the Inner Circle underground railway in London follows a cyclic path.

If, in addition to passing through a *cycle*, the circumstances repeat themselves at regular intervals, and go through the same cycle over and over again, then the process is given the name *periodic cycle.*

We may cause the magnetic force operating on a piece of iron to go through a cyclic change, by first increasing the current through the magnetising coil in one direction till it reaches the highest value we intend to give it, then slowly decreasing it till it reaches zero, going on with it in the reverse direction, and increasing it until it reaches the same maximum value, only with the direction of the lines reverse from that in the first case, and again slowly reducing the current to zero. This will have given us a complete cycle, and the values of the magnetic force and the induction will have gone through a series of changes which represent their cyclic values. If this process be repeated over and over again, we then obtain periodic conditions such as occur with alternating currents. Professor Ewing has designed an instrument by which

such cyclic curves of magnetisation can be drawn. The cyclic curve is shown in Fig. 81, and is of importance because there is a lagging behind of the induction relatively to the magnetic force, and this causes a loss of energy due to a property which is termed *hysteresis*, and which is dealt with in the next paragraph.

100. Hysteresis. Electrical energy is momentarily expended in energising an electro-magnet, quite apart from the constant expenditure of energy in overcoming the resistance of the coils. Part, but not all of this energy, is given out again on demagnetising the coil, in the form of an *extra current*, which is due to the momentary E.M.F. developed by the collapsing lines of the field cutting the turns of the coil (§ 67). The energy absorbed represents work done by the magnetic field of the current, in setting the particles in line against inter-molecular friction.

The definition, *the lagging of a magnetic effect behind its cause*, would seem to give a pretty clear idea of the phenomenon of hysteresis. Magnetisations caused by gradually or periodically increasing currents are always less than the magnetisations resulting from the same currents applied in a decreasing order. In soft annealed iron this molecular friction is very small, hence the hysteresis in such iron is small. In iron that has been hardened in any way, as by drawing, hammering, by the addition of carbon (cast iron), chilling, etc., the friction is greater, and in the case of glass-hardened steel it is very great—so great, in fact,

that it requires a comparatively large magnetising force to turn the molecules at all; but when they are once turned, they remain in their new positions, and we have permanent magnets. The hysteresis in this latter case is enormous. From this it will be seen that hysteresis means lost energy. It only becomes of importance, however, where the magnetising forces vary periodically in strength, as in alternating current work. In transformers, such as are used for transforming alternating currents from higher to lower pressures, or *vice versâ*, the phenomenon of hysteresis is very marked, and every endeavour is made to reduce it as much as possible.

The case we have been dealing with is more specially *static hysteresis*. There is also a lagging behind of the induction relatively to time, and this is termed *viscous hysteresis*. The latter effect is shown by the fact that an iron bar does not magnetise up to its full amount all at once, the induction creeping up slowly till it reaches the value it will take for the magnetic force applied.

101. Hysteresis Curve. Fig. 81 shows the shape of a curve obtained when a sample of iron is subjected to what is called the *cyclic process of magnetisation: i.e.*, the exciting current is sent round the coil one way, the current being gradually increased from zero to a maximum; then gradually decreased again to zero, then reversed and gradually increased, and once more reduced to nil; then again sent in the first direction, until an area is enclosed by the curve. The abscissæ

denote values of H and the ordinates values of B; values of H to the right of the vertical central line being due to a current in one direction, and values to the left of the line to a current in the opposite direction. It will be noticed that the induction (B) starts at O and rises up the inside curve to its highest value; then H is reduced, and B falls along the left-

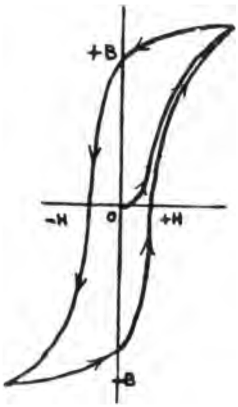


Fig. 81. Cyclic Curve of Magnetisation, or Hysterèsis Curve.

hand curve, H having to be reversed in order to bring B again to zero. When H has been reduced to zero, it will be noticed that there is a considerable value of B in the iron (as at + B in the figure), which is, in fact, the *remanence* or residual magnetism. When the reversal of H has brought B to zero, the value of H required is a measure of the retentiveness or *coercive force* of the specimen. The value of H

being continually increased in the opposite direction, the polarity of the bar is reversed, and the curve of B at last falls to a negative maximum. Now reducing H once more, the curve slightly rises to the right till it reaches a value where H is again zero, *i.e.*, when no magnetising current is passing. The value of B at this point (– B) gives another value for the remanence. Reversing H for the second time, the curve rises sharply upwards and cuts the H line, the distance between this point of intersection and O being a second measure of the retentiveness or coercive force. Continuing to increase H, we finally reach a point where the curve meets the first portion, and an area is completely enclosed. If this cyclic process of magnetisation be repeated, the curve would be retraced over again. Each time the process is gone through a certain quantity of electrical energy is transformed into heat, due to the molecular friction or hysteresis of the bar. The amount of energy thus absorbed is proportional to the area enclosed by the curve, and this would obviously be greater in the case of a steel or cast-iron sample, than with a wrought iron piece. Such a curve is called a cyclic B H, or *hysteresis curve.*

Fig. 82 shows an actual curve taken from a specimen of commercial iron wire in the way described. A coil of 157 turns (No. 18) was wound on a glass tube into which 4 No. 16 iron wires were inserted. The length of the coil was nearly 9·5 inches (24·1 cm.), and its diameter about 1·27 cm. A set of 16 glow lamps (in parallel) and an ammeter were joined up in series with

the coil, and connected with the terminals of a dynamo run at a constant speed: a mercury switch in the circuit enabled the lamps to be inserted or cut out of circuit one by one, and the current strength thus altered; these taking the place of R, G, B, and K in Fig. 79. The

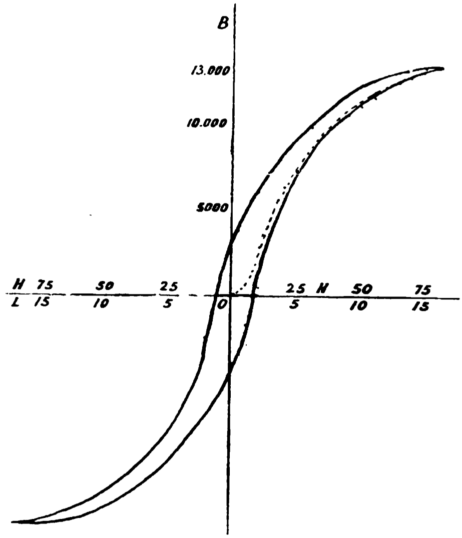


Fig. 82. Hysteresis Curve. (Iron wire sample.)

current was first gradually increased and then decreased, and the result is shown by the curve. The coil and wires under test being placed at right angles with the magnetic meridian, and with the centre of the coil in a line with that of a delicately pivoted magnetic needle provided with a long index (as shown in

Fig. 79), the tangents of the different deflections were taken as being proportional to the values of B: the actual values being afterwards calculated from X., p. 171. (See Ques. 34, page 187.) By means of the ammeter it was ascertained that for each lamp in circuit the current was ·6 ampere; thus when five lamps were in circuit the current was 3 amperes. Knowing this, and the number of turns on the coil, and its length: H was found to be 8·33 for every ampere passed through the coil. (Formula II. § 96.) The number of lamps in circuit (L) is indicated by the lower values along the horizontal line: it should be observed that the values of H are directly proportional to these.

The *permeability curve*, or one giving the values of μ for each value of B for this material, is shown in Fig. 80, the ordinates being obtained by dividing the different values of B by the corresponding values of H, for $\mu = \frac{B}{H}$. From it a good idea can be obtained of what is meant by saturation. At about 5,000 lines of induction per sq. cm. (B), the iron reaches its highest value of μ, and beyond this value its specific magnetic conductance or permeability gradually decreases, the curve bending downwards to the base line. If B were increased to over 40,000, the value of μ would fall to about 2. The curves shown in Figs. 81 and 82 refer to *static hysteresis*: *viscous hysteresis* (already referred to at the end of the previous paragraph) is another effect which shows that the induction lags behind the magnetic force by an interval of time, but gradually creeps

up to its value if the force is steadily maintained for a sufficient period. In other words, in making a B H or hysteresis test, the area enclosed by the curve will be greater if the observations are made directly the current value is altered, than if an interval of time is allowed to elapse before noting the deflection values of the ammeter and magnetic needle. With a given iron core magnetised by an alternating current, the loss of energy due to hysteresis will be greater the higher the frequency of the current (Chap. XI.).

There are other methods of measuring B and μ, such as by means of Silvanus P. Thompson's permeameter, Kapp's magnetic tester, Ewing's magnetic cycle tracer, and his hysteresis measurer. Some of these are briefly referred to in the last paragraph.

The student will now be able to understand why it is that a law similar to that of Ohm for continuous steady currents in a metallic circuit cannot be applied in the case of the magnetic circuit.

$r = \frac{e}{c}$ is true for any value of e or c, provided the circuit does not heat meanwhile: but $\mu = \frac{B}{H}$ is only true for particular values of B and H. Consequently, although $c = \frac{e}{r}$ in all cases, the analogous magnetic formula $B = \frac{H}{R'}$, is only true for a particular value of B, inasmuch as the reluctance (R′) depends upon B, whereas r is quite independent of c in the electric circuit. (§ 95A).

102. Example in Magnetic Calculation.[1]

What are the number of ampere-turns required to magnetise up to 13,500 lines per square centimetre a soft iron ring, 15 inches in mean diameter, made of round iron 1·5 inch thick: the specific magnetic conductance (permeability) of the iron being taken as 900?

The length of the bar to be magnetised $= \pi$ dia. $= 3{\cdot}1416 \times 15$ inches, or $3{\cdot}1416 \times 15 \times 2{\cdot}5$ cms. $= 117{\cdot}8$ cms. $= l$.

$\mathsf{B} = 13{,}500$, and $\mu = 900$.

By formula II. (§ 96) $\mathsf{H} = \dfrac{1{\cdot}257\,\text{CN}}{l}$

where CN are the ampere-turns it is required to find.

Knowing B and μ, we can find H, for $\mathsf{H} = \dfrac{\mathsf{B}}{\mu}$.

$$\text{Thus } \mathsf{H} = \frac{13{,}500}{900} = 15$$

$$\therefore \text{ (by above formula) } 15 = \frac{1{\cdot}257\,\text{CN}}{117{\cdot}8}$$

$$\text{CN} = \frac{117{\cdot}8 \times 15}{1{\cdot}257} = 1406 \text{ ampere-turns.}$$

103. Other Methods of Testing Iron, etc.

Other methods of testing iron depend upon the pull exerted between two bodies, between which there is a slight difference of magnetic potential. A flux through the joint is expressed in lines of induction per square centimetre, B; the total flux will be $\mathsf{B} \times s$, where s is the total cross sectional area in square cms.

[1] Problems of this kind involve an immense amount of labour if worked out by ordinary multiplication and division. The reader is strongly advised to learn the use of tables of logarithms, which can be easily mastered: by their means such calculations as the above are greatly facilitated. Slide rules are also handy for carrying out arithmetical calculations, and present few difficulties in their application.

Then the force in dynes by which they are attracted together will be :—

$$\frac{B^2 s}{8\pi} \text{ dynes.}$$

To reduce to pounds, divide by the number of grammes in a pound, and by the value of g[1]: thus the total pull in pounds is :—

$$\frac{B^2 s}{8\pi \times 453{\cdot}6 \times 981} = \frac{B^2 s}{11{,}183{,}000} \text{ lbs.}$$

Having measured the force in pounds and the area, the induction can be calculated. This is the principle of Hopkinson's arrangement, and of Kapp's modification of and the original Thompson *permeameter.* Hughes, in his earlier experiments, balanced the moment of the electro-magnet (whose core of iron was being tested) by a large permanent magnet, which could be adjusted so as to bring a magnetic needle between the two to zero. The different *ballistic methods* depend upon the measurement of the induced quantity of electricity flowing round the circuit, on the reversal or change in the value of the current through the exciting coil: the quantity of electricity being proportional to the change in the induction. In practice, the ballistic method, with various modifications, has been largely used. Ewing's *magnetic tester* measures hysteresis directly, by the force exerted on a permanent magnet when the iron to be tested is rotated

[1] g is the value (in dynes) of the gravitating force of unit mass (one gramme). It is equal to 981 dynes in England. (§ 7.)

§ 104. Table of Natural Sines, Tangents, etc.

N.B.—*Take the left-hand column of degrees for sines and tangents, and the right-hand column for co-sines and co-tangents.*

Deg.	Sine.	Tangent.		Deg.	Sine.	Tangent.		Deg.	Sine.	Tangent.	
0	0·000	0·000	90								
1	·017	·017	89	31	·515	·601	59	61	·874	1·80	29
2	·035	·035	88	32	·530	·625	58	62	·883	1·88	28
3	·052	·052	87	33	·544	·649	57	63	·891	1·96	27
4	·070	·070	86	34	·559	·674	56	64	·899	2·05	26
5	·087	·087	85	35	·573	·700	55	65	·906	2·14	25
6	·104	·105	84	36	·588	·726	54	66	·913	2·24	24
7	·122	·123	83	37	·602	·753	53	67	·920	2·35	23
8	·139	·140	82	38	·616	·781	52	68	·927	2·47	22
9	·156	·158	81	39	·629	·810	51	69	·933	2·60	21
10	·173	·176	80	40	·643	·839	50	70	·940	2·75	20
11	·191	·194	79	41	·656	·869	49	71	·945	2·90	19
12	·208	·212	78	42	·669	·900	48	72	·951	3·08	18
13	·225	·231	77	43	·682	·932	47	73	·956	3·27	17
14	·242	·249	76	44	·694	·966	46	74	·961	3·49	16
15	·259	·268	75	45	·707	1·00	45	75	·966	3·73	15
16	·275	·287	74	46	·719	1·03	44	76	·970	4·01	14
17	·292	·306	73	47	·731	1·07	43	77	·974	4·33	13
18	·309	·325	72	48	·743	1·11	42	78	·978	4·70	12
19	·325	·344	71	49	·755	1·15	41	79	·981	5·14	11
20	·342	·364	70	50	·766	1·19	40	80	·985	5·67	10
21	·358	·384	69	51	·777	1·23	39	81	·988	6·31	9
22	·374	·404	68	52	·788	1·28	38	82	·990	7·11	8
23	·391	·424	67	53	·798	1·33	37	83	·992	8·14	7
24	·407	·445	66	54	·809	1·37	36	84	·994	9·51	6
25	·422	·466	65	55	·819	1·43	35	85	·996	11·43	5
26	·438	·488	64	56	·829	1·48	34	86	·997	14·30	4
27	·454	·509	63	57	·839	1·54	33	87	·998	19·08	3
28	·469	·532	62	58	·848	1·60	32	88	·999	28·64	2
29	·485	·554	61	59	·857	1·66	31	89	·999	57·29	1
30	·500	·577	60	60	·866	1·73	30	90	1·000	Infinity	0
	Co-sine.	Co-tangent.	Deg.		Co-sine.	Co-tangent.	Deg.		Co-sine.	Co-tangent.	Deg.

between its poles. Dr. C. V. Drysdale has recently invented a most practical form of permeameter, with which any piece of iron or steel, no matter what its bulk or shape, may be tested.

Though this is probably the most difficult chapter in the book, it is certainly one of the most important, and should be carefully studied.[1]

CHAPTER VI.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Describe some method of roughly ascertaining the magnetic qualities of some given samples of iron and steel; as regards their susceptibility to magnetisation, and their retentiveness.

*2. *Define*: remanence, retentiveness, free magnetism, and magnetic conductance.

*3. In choosing metal for a dynamo field magnet, and for a large electric bell, would it matter if that selected had slight retentiveness?

*4. What is the magnetic difference between cast iron and wrought iron?

5. Distinguish between the electric and magnetic circuits, and show how they interlink.

6. Distinguish between paramagnetic and diamagnetic bodies, and between lines-of-force and lines-of-induction.

7. Show how a law, similar to that of Ohm, may be applied

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[1] For extended treatment of the subject of magnetic testing the student should consult Ewing's *Magnetic Induction in Iron and other Metals*, and S. P. Thompson's *Electro-magnet*.

to the magnetic circuit: and show also that it is only roughly correct.

8. Compare the leakage in a magnetic circuit with that in an electric circuit composed of an hermetically sealed battery, and a naked wire immersed in mercury.

9. *Define*: magneto-motive force, reluctance, induction, permeability, and magnetic potential.

10. Given bars of soft iron, cast iron, soft steel, and hardened steel; arrange them in their order of goodness under the following heads:—Permeance, Retentiveness, Reluctance.

11. What is meant by saying that the permeability of soft wrought iron is greater than that of cast iron?

12. *Define*: unit magnetic pole, unit current, ampere, ampere-turns, magnetic force.

13. For what purpose are "curves" used by the engineer, and how are they plotted?

14. What magnetic quantities are denoted by the symbols H, B, and μ; and how are they related to one another? [Ord. 1895.]

15. What is a "curve of magnetisation"?

16. State in your own words what you understand by the term "magnetic permeability."

17. A certain coil of wire carries a constant direct current: how would you ascertain the value of H?

18. What is the magnetic field at the centre of a long solenoid of 250 turns, 3 feet long, and 2 inches in diameter; when a current of 5 amperes is passed through?

19. If you knew any two of the three quantities B, H, or μ, how would you find the third?

20. You are requested to report on some samples of iron furnished to you as intended for electrical engineering purposes. State the experiments you would make, and what special quality you would desire to find present, in order to approve of a sample as good.

21. You are given several samples of wrought and cast iron. How would you proceed to test them, to ascertain which is most suitable for making the field magnets of a small dynamo?

22. Distinguish between permeability and susceptibility.

23. Sketch apparatus which might be used to ascertain the magnetic quality of iron.

24. A closed soft iron ring, 100 centimetres mean circumference and 5 sq. centimetres cross section, is uniformly wound with 200 turns of insulated wire. Suppose you have found that the following relations exist in iron of this quality:—

$B = 10{,}200$	$12{,}000$	$13{,}700$
$\mu = 2{,}000$	$1{,}500$	$1{,}000$

Calculate the current C, at which the total flux of magnetic lines is 65,000 C.G.S. lines. [Ord. 1892.]

25. Calculate the number of ampere-turns of excitation required to magnetise up to 14,000 lines per square centimetre, a soft iron ring, 20 inches in mean diameter, made of round iron 1 inch thick. [Assume permeability =800.] [Ord. 1894.]

26. Distinguish between the energy absorbed in energising an electro-magnet, and that given out on demagnetisation.

27. Explain briefly the reason why reversing the direction of magnetisation of a piece of iron requires a certain expenditure of energy.

28. What do you understand by the term hysteresis?

29. Distinguish between static and viscous hysteresis.

30. Sketch the general form of a curve connecting magnetic force (H) and magnetic induction (B), when taken round a complete cycle.

31. Show the general form of a permeability curve for iron.

32. Evolve formula X., § 97, from the preceding formulæ IV., IX., VIII., and VII.

33. Show that:—

$$\frac{4\pi\, d^3\, \mathrm{H} \tan \mathrm{A}}{\mathrm{V}\,H} + 1 \quad (\text{X., p. } 171)$$

$$= \frac{4\pi\, d^3\, \mathrm{H} \tan \mathrm{A}}{1{\cdot}257\,\mathrm{CN}s} + 1. \quad \text{From II. and VIII. (§ § 96 and 97.)}$$

: both these being values for μ.

34. Show that $B = \dfrac{4\pi\, d^3\, \mathrm{H} \tan \mathrm{A}}{\mathrm{V}} + H.$ (§ 97.)

35. What is the rule for calculating the "intensity" of the magnetic field in the middle of a long tubular solenoid? If the winding is uniform all along, what is the intensity of the field at the open ends as compared with that in the middle? Where must an iron bullet be placed so that the force exerted on it by the solenoid shall be a maximum? [Ord. 1896.]

CHAPTER VII.

The figures refer to the numbered paragraphs.

* 105. Electrical Measurements. The principal electrical measurements with which the elementary student has to deal are those of E.M.F. and P.D., current, resistance, power, energy, magnetic induction, and permeability. The last two are, strictly speaking, magnetic measurements, and were dealt with in the previous chapter. In accurate measurements, it is essential to have *standards* of E.M.F. (or pressure) and resistance, which shall have a known value in volts, or ohms, at a given temperature; and which shall not vary to any great extent with change of temperature, or at least, the variation must be known. A standard of current is also convenient. These standards are considered in the following paragraphs.

106. The Board of Trade Standards. These are the legal standards in Great Britain, and all sub-standards used by the various firms for the graduation of instruments for ordinary use should be compared with them. These standards were legalized on the 23rd August, 1894, and are kept at the Board of Trade offices.

Following are their official definitions :—

(*a*) Standard of Resistance.

"*A standard of electrical resistance denominated one ohm being the resistance between the copper terminals of the instrument marked* "*Board of Trade Ohm Standard Verified* 1894" *to the passage of an unvarying electrical current when the coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of* 15·4C."

(*b*) Standard of Current.

"*A standard of electrical current denominated one amper*

being the current which is passing in and through the coils of wire forming part of the instrument marked "*Board of Trade Ampere Standard Verified* 1894" *when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridio-platinum weight marked* A *and forming part of the said instrument.*"

(c) STANDARD OF PRESSURE.

"*A standard of electrical pressure denominated one volt being one hundredth part of the pressure which when applied between the terminals forming part of the instrument marked* "*Board of Trade Volt Standard Verified* 1894," *causes that rotation of the suspended portion of the instrument which is exactly measured by the coincidence of the sighting wire with the image of the fiducial mark* A *before and after application of the pressure, and with that of the fiducial mark* B *during the application of the pressure, these images being produced by the suspended mirror and observed by means of the eyepiece.*"

The standard of resistance is a special coil of platinum-silver wire, which at a temperature of 15·4°C, offers to a steady current a resistance which is called one ohm.

The standard of current is given as follows :—

A certain balance, similar to a very delicate chemical balance, with a beam 16 in. long, has suspended from one arm a scale-pan, and from the other a scale-pan and a circular coil of wire hung by three gilded phosphor-bronze wires. The current is led into and out from this movable coil by means of spiral wires so arranged as to impede the motion of the coil as little as possible. The movable coil hangs within a fixed marble cylinder supporting two coils, one above and the other below the level of the movable coil. From what is said in § 143, it is evident that when current is sent round the suspended coil in one direction, through the lower fixed coil in the same direction, and through the upper fixed coil in the opposite direction, the movable coil will be repelled by the upper fixed

coil and attracted by the lower one, this force being proportional to the square of the current. If the current in the fixed coils is reversed, the movable coil will tend to move upwards. Thus, it is that the current can be measured by the weight required to be put into the scale-pan in order to keep the beam of the balance in its horizontal position. There is a certain iridio-platinum weight marked A, of such a mass that when it is put into the scale-pan on the same end of the beam as the coil, a current (passing round the coils) the effect of which exactly counterbalances it under certain conditions is equal to one ampere.

The method of using the instrument is as follows. As we have said before, there is a scale-pan at each end of the beam. Call the one at the same end as the coil SC, and the other S. An approximate current of one ampere is passed through the coils in such a direction that the movable coil is drawn downwards, and this force is counterbalanced by placing weights in the scale-pan S. The current is then adjusted to the value of one ampere, as indicated by an auxiliary instrument (which is known to be fairly correct), and the balance is exactly adjusted. A switch which reverses the current in the fixed coils is then operated, the movable coil thus tending to move upwards; but at this moment the weight A is lowered by a special device into the scale-pan SC. If on doing this the balance is still exactly maintained, the current is one ampere.

The standard of pressure is one hundredth of the 100 volts as indicated by a specially designed multicellular voltmeter, an ordinary type of which is illustrated and described in § 131. This special instrument has ten vanes suspended by an iridio-platinum wire 18 cm. long. The movable portion carries a concave mirror, and the zero and standard deflectional positions of the vanes are indicated by the reflection of certain lines (fiducial marks) on fixed portions of the instrument, the reflection being observed by a telescope fixed to the stand. Before taking a reading, the vanes and quadrants are connected together to neutralize any existing P.D. between them, and the vanes are carefully adjusted to the zero position, as indicated by

the sighting of the zero fiducial mark by the telescope. Pressure is then applied and adjusted until the vanes have steadily taken up that position which enables the second fiducial mark to be seen. If this position is maintained, the P.D. between the vanes and the quadrants is exactly 100 volts.

107. Test Room Standards. For general test-room work it is necessary to have fairly reliable and inexpensive standards. Standards of resistance are easily constructed (§ 108). A standard of pressure is obtainable from the well known *Clark standard cell*, which gives an E.M.F. of 1·434 volts at 15° C. (59° F.): this should only be used on open circuit, or with high resistances in circuit. There are also various forms of the Daniell cell used as standards. As a standard of current, it is convenient to remember that one ampere will deposit silver in a properly constructed voltameter at the rate of ·001118 grammes per second.

* 108. Standard Resistance Coils. Standard resistance coils have some known value in ohms at a given temperature, and are generally made of *manganin*, *platinoid*, *platinum-silver*, or *german silver*[1] wire covered with white silk. Manganin wire is suitable for most coils, as it has the highest specific resistance, and changes the least with change of temperature. The wire is previously baked in an oven and boiled in paraffin wax, to get rid of moisture and improve the insulation of its covering.

It is important that resistance coils for measurements should have no inductance, and it will be clear

[1] For composition of alloys, see § 21.

that by doubling the wire upon itself (Fig. 83), each half of the coil neutralises the other's magnetic effect, and consequently there is no self-induction or inductance. The coil is wound upon a bobbin, and after being again dipped in paraffin wax, is enclosed in a brass case, the ends of the coil terminating in thick copper legs (Fig. 84). Only comparatively small currents must be passed through standard resistance coils, else the heat evolved will alter the resistance of

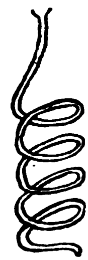


Fig. 83. Coil without Inductance.

Fig. 84. Standard Resistance Coil.

o

the coil. In the form shown, the wire (of platinum-silver) is wound in a flat double spiral, and enclosed in a thin, flat, watertight box, so that it may be immersed at one level in a water bath. The coil quickly takes the temperature of the water, owing to the large surface exposed, and its flat shape. The coil is correct at a certain temperature, generally 15° C, and the temperature is shown by the thermometer, whose bulb is

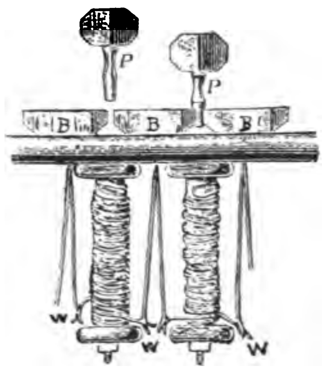


Fig. 85. Resistance Coils.

in the coil. To prevent surface leakage between the copper arms, a cup to contain paraffin is formed at the top of the brass case.

* 109. Resistance Coils, etc. Resistance coils for ordinary measurements are made of one or other of the above-mentioned wires, and are generally mounted in boxes as shown in Figs. 85 and 91. The brass blocks *B B B* are in connection with the coils through the

wires *W W W*. By means of the brass plugs *P P*, any coil can be inserted or cut out from the circuit at will.

It is often required to insert resistances in a circuit for the purpose of absorbing power or cutting down the current. It is seldom necessary to know their exact value, but they must be capable of adjustment to higher or lower values. Coils of iron wire, incandescent lamps in parallel (§ 101), carbon or lead electrodes dipping into dilute sulphuric acid, etc., are useful for this purpose.

* 110. Measurement of Resistance by Substitution.

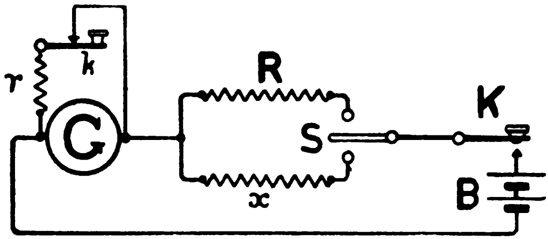


Fig. 86. Measurement of Resistance by Substitution.

This method of measuring resistance, otherwise known as the *reproduced deflection method*, is as follows:—*G* (Fig. 86) is a fairly sensitive galvanometer, *R* a resistance box, *x* the resistance to be measured, *S* two-way switch, *K* key, *B* a constant battery of 2 or 3 Daniell cells, and *r* an adjustable resistance shunting the galvanometer, by means of which the sensibility of the latter may be varied. This shunt *r* may be removed by depressing the *top contact key k*.

Place the switch S so as to include the unknown resistance x in circuit. Depress the key K, and alter the value of the shunt r until a convenient deflection of G is obtained. If x is small and the current flowing round the circuit consequently great, r must be small, otherwise too much current will go through the galvanometer, and the needle move too far. On the other hand, if x has a high resistance the current will be proportionally small, and it will be necessary to increase r so as not to shunt too much current from

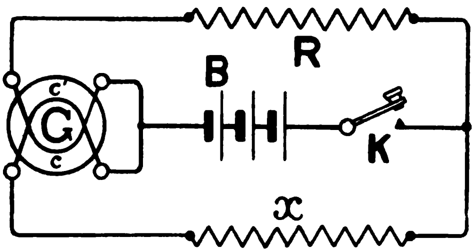


Fig. 87. Measurement of Resistance by the Differential Galvanometer.

the galv., or to cut r out altogether by means of the key k. When r is adjusted, note the deflection on G. Now put R in circuit, and alter its value until the same deflection is obtained on G, without altering r or k.

Then :— $x = R$.

* 111. Measurement of Resistance by the Differential Galvanometer. In Fig. 87, G is a differential galvanometer, *i.e.*, one wound with two separate coils of equal length and resistance. With such, a current

in one coil will not affect the needle if at the same time a current of equal. value is passing through the other coil in the *opposite* direction. B is a battery, (three or four Leclanché cells for instance), K a key, R an adjustable known resistance, and x the unknown resistance. Depress K and adjust R until no deflection is obtained on the galv. Call one of the galvanometer coils c, and the other c'. Then because each circuit B, c, R, and B, c', x, has a common E.M.F. due to B; and because equal currents are flowing round both circuits (otherwise the galv. would give a deflection); the resistance of each circuit must be equal, by Ohm's law. The internal resistance of B, being common to both circuits, may be neglected.

$$
\begin{aligned}
\text{Then since}\quad & \mathrm{c} + \mathrm{R} = \mathrm{c}' + x \\
\text{and}\quad & \mathrm{c} = \mathrm{c}' \\
\therefore\quad & x = \mathrm{R}
\end{aligned}
$$

The methods of measuring resistance described in this and the preceding paragraph are frequently employed in practice for ordinary testing purposes: and, with skilled observers, give accurate results.

* 112. THE WHEATSTONE BRIDGE. The principle of the Wheatstone bridge is as follows. If, as in Fig. 88, a current divides at A between the two branches $b\,x$ and $a\,R$, reuniting at B; it follows that no matter what may be the relation between the resistance of $b + x$ and $a + R$, there must be an equal fall of potential along the paths $A\,b\,x\,B$ and $A\,a\,R\,B$. If a galv. G be connected at a point C in $b\,x$, then by experiment a point

D in $a\,R$ may be found such that no deflection is given on the galvanometer, and it then follows that the points C and D are at equal potentials. This being the case, if it is known that :—

$$b + x = a + R,$$
$$\text{then } b = a$$
$$\text{and } x = R.$$

In any case it follows that :—

$$b : a :: x : R.$$

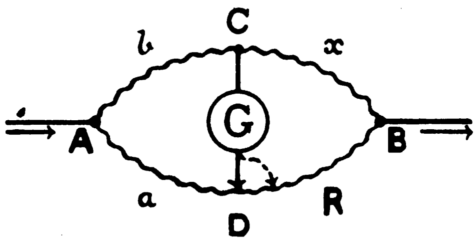


Fig. 88. Diagram illustrating the principle of the Wheatstone Bridge.

Fig. 89 illustrates diagrammatically the arrangement of a Wheatstone bridge. a, b, and R are sets of resistance coils, and x is the resistance to be measured. a and b are called the *ratio arms of the bridge*, and are either equal or bear some decimal proportion to each other. G is a galvanometer, *BATT.* a battery, and $G\,K$ and $B\,K$ keys in the galvanometer and battery circuits respectively. R is adjusted until, on depressing the keys, no deflection is obtained on the galvanometer.

Then if a and b are equal,

$$R = x$$

Otherwise as:— $a : b :: R : x$

$$x = \frac{b}{a} R$$

Fig. 89 should be compared with Fig. 88, the ar-

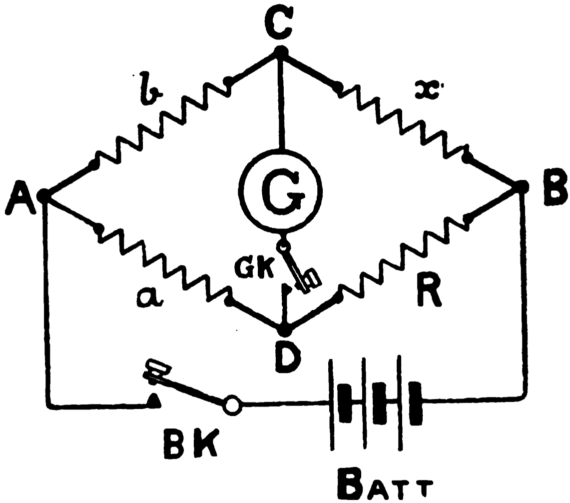


Fig. 89. The Wheatstone Bridge.

rangement, lettering, and explanation being similar; except that in the latter case G is connected with fixed points in the circuit.

The resistance to be measured generally has some inductance, especially if it be an electro-magnet; so to prevent the induced momentary E.M.Fs. due to this

from disturbing the proper action of the galvanometer, a key is inserted in the galvanometer circuit, as well as in the battery circuit, these being shown at *G K* and *B K* in Figs. 89, 91, and 92. In making a test, the battery circuit should be closed *before* and broken *after* the galvanometer circuit.

Keys have been devised which only require one motion to effect these connections in their proper order. Such a key is known as a *double-contact* or *successive-contact* key, and is diagrammatically represented in Fig. 90, which clearly shows how it would be joined up in the Wheatstone Bridge circuit (Fig. 89). *i* is an in-

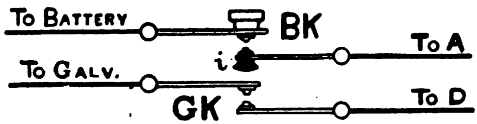


Fig. 90. Successive-Contact Key.

sulating knob which prevents contact between the two keys.

Fig. 91 represents a form of Wheatstone bridge apparatus. In portable testing sets (§ 123) the galvanometer is frequently included in the case that carries the coils. For laboratory work the galvanometer is generally more sensitive, a mirror instrument being used in such cases. Any fairly sensitive galvanometer will do for ordinary measurements, as it is only required to prove the equality of pressures at its terminals, *i.e.* the *absence* of a current through it.

In Fig. 91 it will be noticed that two separate keys

are used instead of a double-contact key (Fig. 90), and this is the common practice. The right and left hand keys correspond with $B\,K$ and $G\,K$ respectively (Figs. 89, 90, and 92). The six back plugs represent the arms (a and b) of the bridge, three on one side and three on the other, while of the remainder 16 represent resistances in R, and 2 are disconnecting plugs.

The arrangement of the resistance coils will be seen

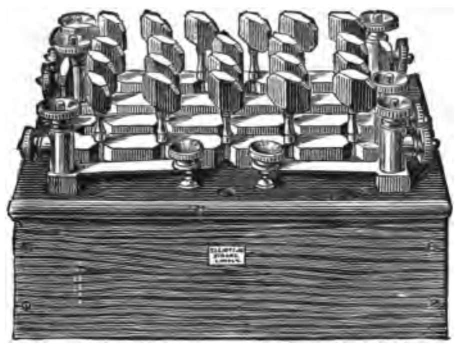


Fig. 91. Wheatstone Bridge (Post Office pattern).

from Fig. 92; but some boxes have less and some more coils, and their arrangement and resistance values also vary in different makes.

Fig. 92 is virtually a plan of Fig. 91, with the outer connections shown. It should be compared with Fig. 89. It will be seen (Fig. 92) that there are two plug-holes marked INF. (Infinity). There is no wire connected across these, and consequently parts of the bridge may be entirely disconnected from one another.

Sometimes a reversing switch is put in the battery circuit, but this is not essential in ordinary measurements.

The common forms of Wheatstone bridge may be used to measure resistances from fractions of an ohm up to values approaching a megohm: the best range being from say 1 ω to 100,000 ω.

113. THE SLIDE-WIRE OR METRE BRIDGE. The slide-

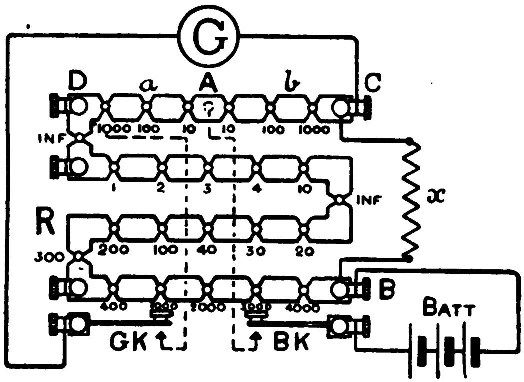


Fig. 92. Arrangement of Coils in Wheatstone Bridge.

wire or metre bridge is the same in principle as the Wheatstone bridge. Referring again to Fig. 88, if one end of the galvanometer circuit be fixed at any point C in $b\,x$, a point D may be found in $a\,R$, such that the potentials at C and D are equal, as indicated by the non-deflection of the galvanometer.

Then:— $a : b :: R : x$

Suppose b is a known resistance, x the unknown

resistance, and $a\,R$ a stretched wire of uniform resistance whose value need not be known: then if the galv. is permanently connected at C, while its other end D is capable of being slid along $a\,R$, a point D will be found where balance is obtained. Then a and R being parts of one uniform wire, their resistances must be proportional to their lengths, so that it is only necessary to know the lengths $A\,D$ and $D\,B$ when balance is

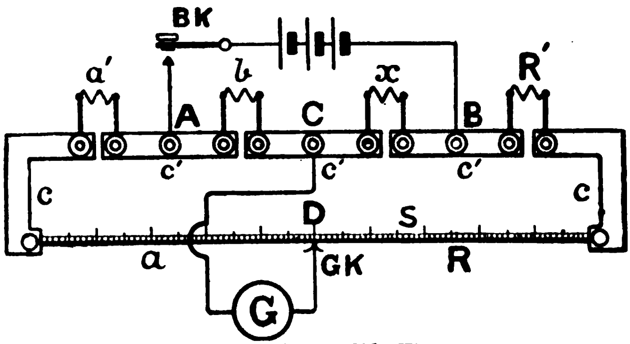


Fig. 93. Diagram of the Slide-Wire Bridge.

obtained. This is the principle of the metre bridge, and is more clearly indicated in Figs. 93 and 94.

Fig. 93 shows diagrammatically the construction of the ordinary form of slide-wire bridge. $a\,R$ is a uniform wire, generally, but not necessarily, one metre long. This wire is made of platinum, or better still, of platinum-iridium, which alloy is harder and more able to withstand wear. $a\,R$ is stretched alongside a scale S, and connected at its ends to two massive copper strips $c\,c$; other copper strips $c'\,c'\,c'$ are arranged as

shown, and the whole is mounted on a long mahogany base. The copper strips carry the various terminals. One end of the galv. G is connected with the centre terminal at C, and the other with a special form of *sliding key* $G\,K$, which may be slid along the scale S, and depressed to make contact at any point D in $a\,R$. The battery and battery key $B\,K$ are connected, as shown, to the terminals at A and B.

The simplest method of using this apparatus is as follows:—short-circuit those terminals between which a' and R' are connected (Fig. 93); insert a known resistance at b, and the unknown resistance at x, b being approximately equal to x: manipulate the sliding key $G\,K$ until the galv. gives no deflection, when $B\,K$ and $G\,K$ are successively depressed.

$$\text{Then :—} \quad a : b :: R : x$$

$$\textit{i.e.} \quad x = \frac{R}{a}\, b \text{ (ohms).}$$

The wire $a\,R$ being uniform, the comparative resistances of the lengths on either side of the point D where $G\,K$ makes contact, may be expressed by the lengths (say in cms.) of a and R as shown by the scale. b, which is generally a standard resistance coil, is expressed in ohms; and the value obtained (x) will therefore be in ohms.

A better and more accurate method of using the apparatus is to insert known resistances at a', b, and R', the unknown resistance at x, and proceed as before. a' and R' should have about the same value, if b can be

made approximately equal to x. Then when balance is obtained:—

$$a + a' : b :: R + R' : x$$

$$i.e. \quad x = \frac{(R + R')}{a + a'} b \text{ (ohms).}$$

b is expressed in ohms, and a, a', R, and R' in cms., the values of a' and R' (in terms of the number of cm.

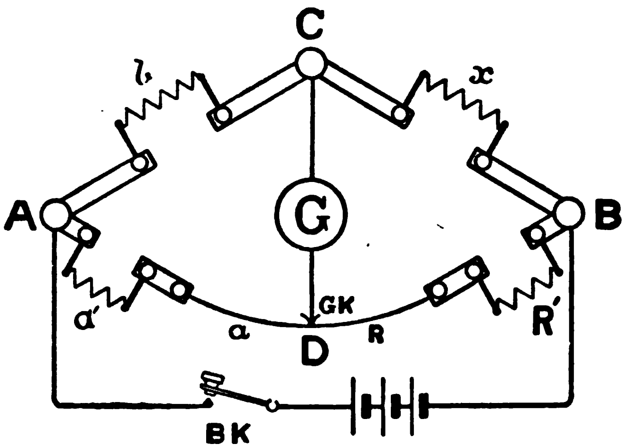


Fig. 94. Comparison between Wheatstone and Slide-Wire Bridges.

divisions along the wire a R to which their resistances are equal) having been previously found. a' and R' are, in fact, merely prolongations of the arms a and R.

114. Comparison between the Wheatstone and Slide-Wire Bridges. The difference between the Wheatstone and slide-wire bridges is briefly as follows. Referring to Fig. 88, in the Wheatstone

bridge the galvanometer is connected to two fixed points *C* and *D*; and *b*, *a*, and *R* are adjustable resistances. In the slide-wire bridge the galvanometer is permanently connected at *C* only, *b* being generally a fixed resistance, and *a R* wholly or partly a stretched wire with which the galvanometer makes contact at some point *D*.

This comparison between the two bridges will be better understood from Fig. 94, which represents the slide-wire bridge set out diagrammatically to correspond with Fig. 89. *a R* is the stretched wire, and *a′ R′* the resistances which are sometimes dispensed with. Figs. 88, 89, 92, 93, and 94 all have the same parts, which are similarly lettered, and they should be carefully compared one with another.

115. POTENTIOMETERS. There are a number of instruments of various patterns for measuring E.M.F., P.D., and current, whose action depends upon the fact that there is a uniform fall of electrical pressure or potential along a conductor of uniform resistance. Such are called *potentiometers*.

POTENTIOMETER METHOD OF MEASURING E.M.F. *A B* (Fig. 95) is a wire of uniform material and cross section, its resistance will therefore be uniform and proportional to its length. It should be of platinum-iridium or manganin. A scale is fixed alongside *A B* so that the distance of any determined points in the wire from either end may be at once ascertained. *G* is a galvanometer, *S* a suitable standard cell of known E.M.F., *K* a tapper key which may be slid along *A B*, *Sw* a

two-way switch or key, and x the battery whose E.M.F. is required.

A current is sent along $A B$ from some convenient source (such as a secondary battery), and a constant fall of potential maintained along it. Sw is placed so as to connect G with x, and K is slid along $A B$ until a point K is found, such that there is no deflection of G: then we know that the tendency of the P.D. between K and B (due to the current in $A B$) to send a current

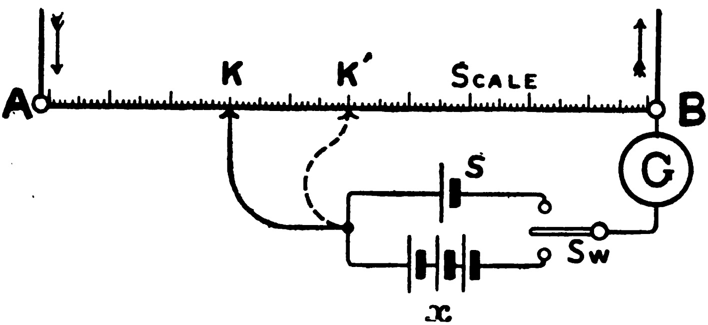


Fig. 95. Potentiometer method of measuring E.M.F. or P.D.

round the bye circuit $K x G B$ is exactly balanced by the E.M.F. of x. In the same manner, Sw being placed to connect G with S, a point K' is found with the same key, such that the P.D. between K' and B is exactly counterbalanced by the known E.M.F. of S.

It then follows that:—

Known E.M.F. S : unknown E.M.F. x :: P.D. $K'B$: P.D. KB.

But P.Ds. along $A B$ are proportional to lengths

Therefore :—

$$S : x :: \text{length } K'B : \text{length } KB$$

$$i.e.\ x = \frac{KB}{K'B} S \text{ (volts.)}$$

KB and $K'B$ being expressed in cms., and S in volts.

POTENTIOMETER METHOD OF MEASURING CURRENT. For the measurement of current the arrangement of apparatus is as shown in Fig. 96. AB is the potentio-

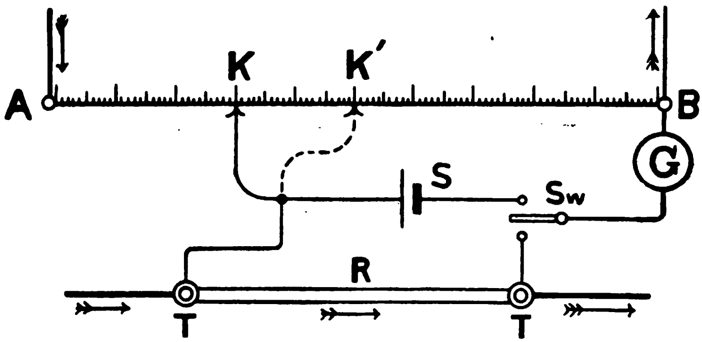


Fig. 96. Potentiometer method of measuring Current.

meter wire as before. R is a platinoid strip of known resistance R (ohms), and of sufficient cross section to carry the current to be measured without heating; the current-carrying circuit being connected to the terminals TT. G is a galvanometer, S a standard cell of known E.M.F., K a sliding key, and Sw a two-way switch or key.

When the current to be measured flows along R, there is a greater or less P.D. between its ends, and this

is balanced against the fall of potential in $A\,B$ by means of the sliding key K and the galv. G; the switch Sw being on the lower contact. Now put S in the galvanometer circuit by means of Sw, and find a point K' with the same key, such that P.D. between $K'B$ balances the E.M.F. of S.

Then it follows that:—

$$\text{P.D. on } R : \text{E.M.F. } S :: \text{length } K\,B : \text{length } K'B$$

$$\textit{i.e.}\ \text{P.D. on } R = \frac{K\,B}{K'B} S \text{ (volts.)}$$

$K\,B$ and $K'B$ being expressed in cms., and S in volts.

The resistance of R being known, the current flowing through it can at once be ascertained, for:—

$$\text{Current in } R = \frac{\text{Fall of potential along } R}{\text{Resistance of } R.} \quad (\S\S\ 31, 47)$$

Thus:—

$$\text{Current in } R = \frac{K\,B \times S}{K'B \times R \text{ (ohms)}} \text{ (amperes.)}$$

The wires from the galv., switch, and sliding key should be so connected to $T\,T$ that any possible bad contact between the main leads and the terminals $T\,T$ may not be included in the potentiometer circuit.

In comparing the two methods, it should be observed that the current-carrying strip R in the test for current takes the place of the battery x in the test for E.M.F.

* 116. Galvanometers. Of these there are many different kinds. Without entering into a full discus-

sion of the various principles on which they are constructed, it must suffice to explain briefly five typical varieties :—

(*a*) The ordinary detector.
(*b*) The astatic detector.
(*c*) The moving-magnet galvanometer } Mirror or reflecting galvanometers.
(*d*) The moving-coil galvanometer } Mirror or reflecting galvanometers.
(*e*) The tangent galvanometer.

* 117. THE ORDINARY DETECTOR (Fig. 97). This

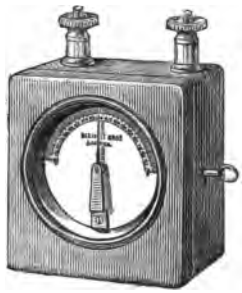


Fig. 97. Ordinary Detector.

consists of a vertical magnetic needle mounted on a horizontal spindle which carries at one end the blackened brass pointer seen in front of the dial. The needle is surrounded by a coil of wire whose ends are joined to the terminals on the top of the case.

Sometimes two separate coils of wire are wound on the instrument, one having few turns of comparatively thick wire, and the other many turns of fine wire (for

reasons given in § 86). In this case the detector has three terminals, the ends of the short coil being usually joined up to the terminals 1 and 2, and those of the long coil to terminals 2 and 3: or one end of each of the coils is joined up to one terminal, and the other ends of the two coils to the other two terminals.

Such an instrument as this is invaluable for numerous rough tests for continuity, breaks, short-circuits, etc., and for ascertaining the condition of batteries.

* 118. THE ASTATIC DETECTOR (Fig. 98). As its

Fig. 98. Astatic Detector.

name indicates, this has two magnetic needles arranged astatically, *i.e.*, parallel with each other and with unlike poles opposite. These needles, and the pointer seen in front of the dial, are mounted on a vertical spindle turning in jewelled centres. One of the needles is within the coil, and the other between the top of the coil and the dial. Two terminals mounted on ebonite blocks on the outside of the case are connected with the ends of the coil. Although the needles are astatically arranged, they are not equally mag-

netised, and therefore not perfectly astatic, so that the Earth is able to exercise sufficient force to keep them in the north and south direction when no current is passing.

This instrument is often wound to a resistance of about 1,000 ω, so that it has some thousands of

Fig. 99. Reflecting or Mirror Galvanometer.

turns of wire on its coils: this, and the delicacy with which the needles are pivoted render the instrument sensitive to small currents. It is suitable for rough Wheatstone bridge tests, and could be used in the substitution method of measuring resistances. When wound with two coils, it forms a handy differential galvanometer of fair accuracy. Being very portable,

it is specially adapted for outdoor testing, and is generally provided with a leather case and strap.

* 119. THE REFLECTING GALVANOMETER (MOVING MAGNET). One of the numerous forms of this instrument is shown in Fig. 99. Fig. 100 shows, enlarged, the movable portion carrying the mirror *M* by which the beam of light thrown from a lamp is reflected back on to a scale. Thus the very slightest movement of *M* results in a perceptible deflection of the spot of light on the scale, which may be 3, 4, or more feet distant from the galvanometer. The reflected beam of light acts as a long weightless pointer.

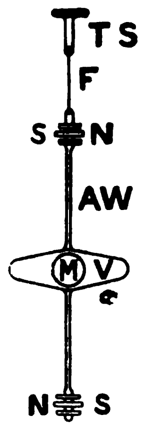


Fig. 100. Needles and Mirror of Reflecting Galvanometer.

Referring again to Fig. 100, *A W* is an aluminium wire which carries the two compound magnetic needles *S N*, *N S*, (which it will be noticed are astatically arranged), the vane *V* of aluminium foil, and the mirror *M*. *A W* hangs from a thumb-screw *T S* by a very fine fibre *F* of cocoon silk.

The top and bottom coils (Fig. 99) are made in two halves, and mounted on hinged frames; which arrangement enables the needles, etc., to be easily got at for inspection or adjustment. There are thus really four coils, which are connected up in series to the two terminals. The instrument requires carefully levelling, that the needles and vane may hang quite clear;

this operation is easily effected if the coil frames be opened out to allow the suspension to be seen. When the instrument is set up, *V* turns in a small and almost airtight chamber, so that it "damps" or retards the oscillations of the galvanometer needles.

Such a galvanometer as this is well suited for Wheatstone and metre bridge, and potentiometer tests.

Fig. 101. Holden-D'Arsonval Galvanometer.

* 120. THE REFLECTING GALVANOMETER (MOVING COIL). A useful form of this class of instrument is that known as the *Holden-D'Arsonval Galvanometer*, which is shown in the following figures.[1] The principle of *moving- or suspended-coil galvanometers* is very much

[1] Figs. 101–105 originally appeared (unlettered) in the *Electrician*.

the same as that of an electric motor, except that there is no commutator or brushes. If a coil of wire is placed in a magnetic field, and a current is sent through the coil, the latter will tend to move round in the field in a direction depending on the direction of the current and of the field (Chap. XIII.).

The galvanometer with cover removed is shown in Fig. 101. A front elevation is given in Fig. 102, a

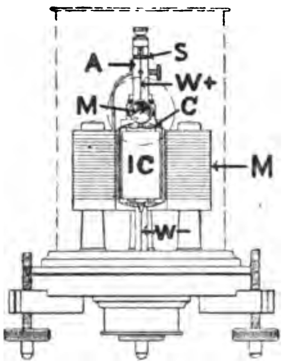


Fig. 102. Holden-D'Arsonval Galvanometer (Elevation).

plan in Fig. 103, while the coil and frame are shown separately in Fig. 104.

M is a circular compound permanent magnet, in the field of which is slung the coil *C* by the flat phosphor-bronze wires *W* + and *W* −. These wires serve also to lead the current into and out from the coil: the ends are held fast by suitable pinching nuts at top and bottom, and the tension may be adjusted by means of the screw *S*. The coil *C*, of several turns of fine

wire, is wound on a light silver frame F (Fig. 103), which, forming a closed circuit of little resistance, tends to damp the oscillations of the coil; for while the coil is moving, currents are induced in this frame, which in accordance with Lenz's law (§ 65), tend to stop the motion producing them, though of course this inductive action, being only momentary, does not affect the ultimate position taken up by the coil. The flat strip or wire suspension tends to keep the coil with its plane

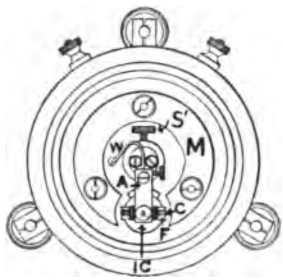


Fig. 103. Holden-D'Arsonval Galvanometer. (Plan.)

parallel with the field, and it is against the torsion of this strip that the coil is deflected. M (Figs. 102 and 104) is the mirror whereby the movements of the coil are shown on a scale, in the manner described in the preceding paragraph. IC is a soft iron core by which the field of the magnet is concentrated. By loosening the screw S', and releasing the wire W, which is connected with one of the terminals, the coil, frame, and core may be removed bodily from the main portion of the instrument (Fig. 104). This renders the repair or

adjustment of the suspension very easy. The mounting of the coil and frame, etc., is well shown in Figs. 101 and 103. The top angle-piece *A*, which supports the upper end of the coil, is insulated from the lower portion of the frame by the insulating pieces *B*. *A* is connected by the wire *W* (Fig. 103) with one of the terminals, while the other terminal is in connection with the lower end of the coil through the framework and lower angle piece *A′*. The instrument we have just described is clearly only available for direct cur-

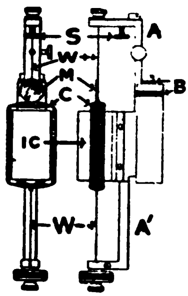


Fig. 104. Holden-D'Arsonval Galvanometer. (Coil holder.)

rents. For alternating-current work, recourse is had to the hot-wire principle, in which case the permanent magnetic field is not necessary. The plug *P* (Fig. 105), which supports the device, is, however, made to fit into the ordinary socket and stand, the presence of the magnet making no appreciable difference in its action. The two wires *W W′* have the same rate of expansion, so that under ordinary atmospheric changes of temperature the position of the mirror *M* is not affected. The front wire *W* does not

carry the current, it being insulated at its lower end: at its middle it carries a small spindle *S*, to which *M* is attached. On this spindle and below *M* are wound a few turns of fine silk thread *S′*, the other end of which is connected to the current-carrying wire *W′* by a wire loop *L*. A tightening screw (torsion head) *T S* enables a twist to be given to the front wire so that it pulls on *W′*. A current passing through the latter

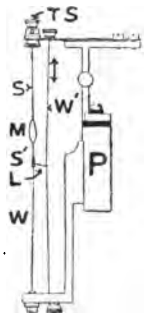


Fig. 105. Holden Hot-wire Galvanometer.

heats it more or less, and enables it to "give" to this pull, thus allowing the mirror to turn slightly.

* 121. GALVANOMETER LAMP AND SCALE. In ordinary work a paraffin lamp is employed, and its attendant disadvantages of dirt, smell, and smokiness are very out of place in a test room. Fig. 106 shows a convenient form of lamp and scale[1] in which a small incandescent lamp is used, the latter being

[1] Made by Mr. Hicks, of Hatton Garden, London.

worked from a two-cell secondary battery. The standards supporting the lamp and scale have a sliding vertical adjustment, and are hinged to the weighted base, so that the whole may be folded up to go into a convenient leather case supplied by the makers. The focussing tube, carrying the lamp at one end and a double convex lens at the other, is mounted on a ball

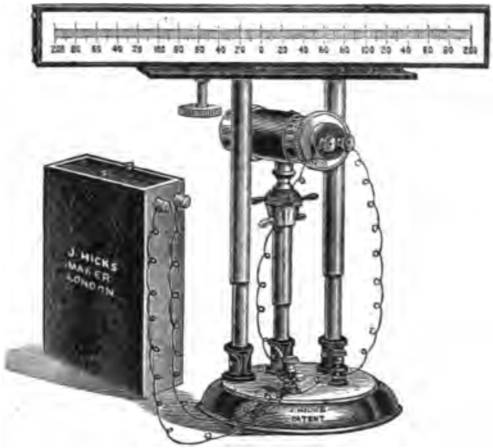


Fig. 106. Reflecting Galvanometer Lamp and Scale.

joint, which may be locked by slightly turning the projecting knobs. The lamp is fixed on an ebonite block carrying two terminals, and having a bayonet joint fitting to the focussing tube. The horizontal adjustment of the ground glass scale is obtained by a pinion and rack, operated by the thumb-screw seen in the figure. The above apparatus is certainly very

convenient; but a celluloid scale would be better than the easily broken glass one.

Transparent scales are used when the lamp and scale are placed between the galvanometer and the observer; but generally the latter stands between the instruments, in which case a cardboard scale may be used. In most situations it will be found more satisfactory to dispense with the secondary battery, use a larger incandescent lamp, and take the current from supply mains.

122. THE TANGENT GALVANOMETER. A knowledge of the principles of this instrument is important to the elementary student, though it is not now used to any great extent in heavy electrical engineering work.

If we take a circular coil of wire of one or any number of turns, and of a diameter of not less than say about 8 inches, when a current passes through the coil, it must be evident that the field in the centre is fairly uniform, that is, that the lines are straight and parallel with each other. If a relatively small magnetic needle (say not more than $\frac{3}{4}$ in. long) be freely hung or pivoted at the centre of the coil, however much it turns it will be wholly in a uniform field, which will therefore exert a force in one constant direction upon it, the amount depending on the strength of the current. If a large controlling magnet be placed so that its field is at right angles with the field of the current in the coil, it will also exert a constant unidirectional force upon the needle: or instead of a controlling magnet, the Earth's force alone may be allowed to act on the

needle, in which case the galvanometer coil must be put with its plane in the magnetic meridian.

Now when a rigid bar, such as a magnetic needle, is acted upon by two forces exactly at right angles with each other, it will obviously take up an intermediate position between the two directions. If acted upon by the *controlling force* alone (the controlling magnet's or Earth's field), it will point in the direction of that force, and this is its zero position. When the current's *deflecting force* acts, the needle will move round over a certain number of degrees, and come to rest at a certain deflection δ.[1] The ratio of the deflecting force to the controlling force is :—

$$\text{deflecting force} = \text{controlling force} \times \tan \delta$$

$$\text{or} \quad \frac{2 \pi C N}{r} = H \times \tan \delta$$

$$\text{That is,} \quad C = \frac{H r \tan \delta}{2 \pi N} \times 10 \text{ (amperes.)}$$

Where :—

δ = deflection of needle, in degrees,
r = radius of coil, in cms.,
N = no. of turns in coil,
H = strength of controlling field, in dynes,
C = current.

As these values alone would give the current in G.G.S. units, they are multiplied by 10, as shown, to bring C to amperes (§ 92).

Tan δ signifies the tangent of the angular deflection δ, which is procurable from a table of tangents (§ 104)

[1] Greek *delta*.

With any given tangent galvanometer the value $\frac{r}{2\pi N}$ is a constant; and the comparative strengths of two currents are then as the tangents of their angles of deflection. Supposing one current C produces a deflection of 39°, and another C' a deflection of 27°; their comparative strengths are not as 39° is to 27°, but as tan 39° is to tan 27°, or :—

$$C : C' :: \tan 39° : \tan 27°$$
$$:: \cdot 810 : \cdot 509$$
$$i.e.\ C = \frac{\cdot 810}{\cdot 509} C' = 1\cdot 59\, C'.$$

123. Portable Testing Set. One of the best of several forms of handy testing apparatus is that known as the *Silvertown Portable Testing Set.* This consists of a box containing resistance coils, galv., and key, etc. (Fig. 107); and another box (not shown) holding two separate batteries. The two tests for which this apparatus is most often used are those of (*a*) resistance of conductor, and (*b*) resistance of insulation. One battery of four low resistance Leclanché cells, called the "bridge battery," is used for the first measurement; while for the second, a battery of 30 small Leclanché cells, which may be subdivided into three sections of 10 cells each, is provided; this latter being called the "insulation battery."[1] Either of the batteries is connected with the resistance box by

[1] In the latest form, the two batteries consist of 3 and 36 cells respectively.

means of flexible conductors and plugs, as seen in Figs. 107, 109, and 110.

Fig. 108 is a diagram showing the whole of the connections of the test box (Fig. 107), and the reader should carefully compare these two figures. In parti-

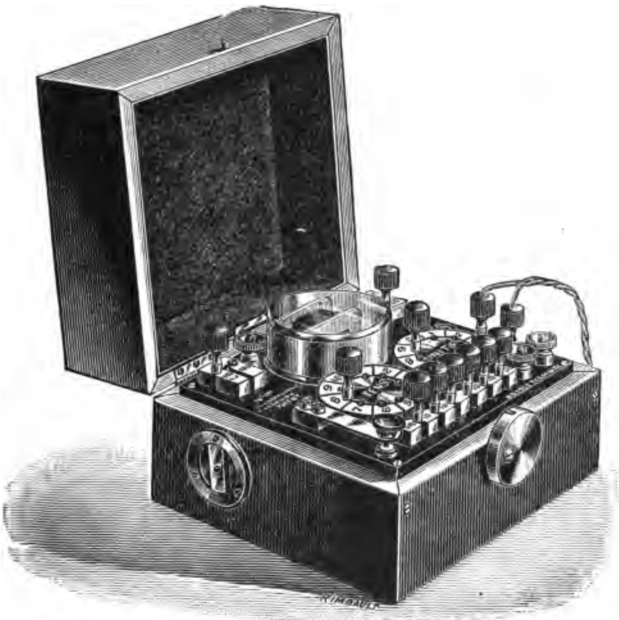


Fig. 107. Silvertown Testing Set.

cular the connections of the *dial arrangement* of resistances should be noted. There are two "dials" marked respectively UNITS and TENS; each coil of the former has 1ω, and each coil of the latter 10ω. One plug only is

necessary for each dial, and to put in any required resistance the plug is *inserted* in the socket opposite the number required; the arrangement is thus the reverse

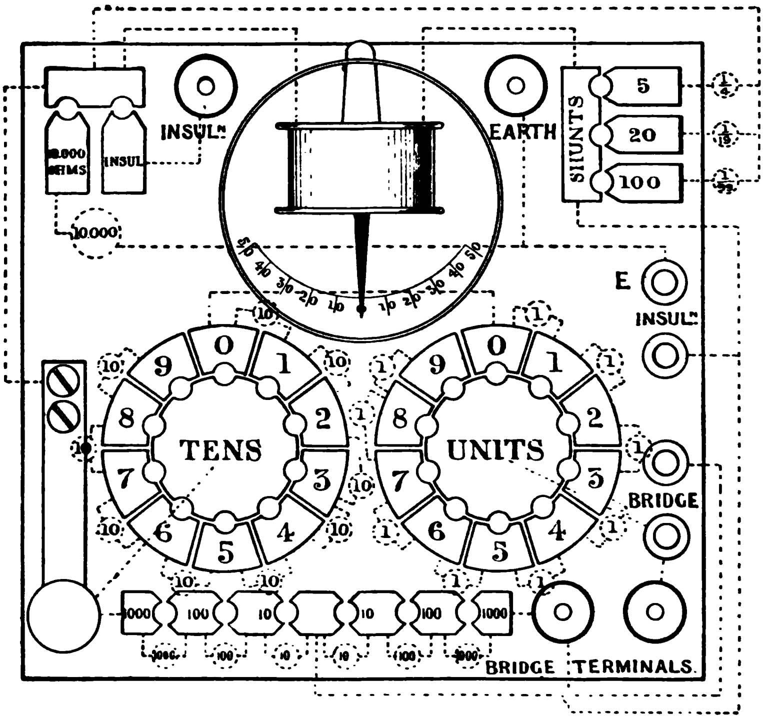


Fig. 108. Silvertown Testing Set. (General connections.)

of that shown in Fig. 91, and in the bottom coils of Fig. 108, where the insertion of a plug *cuts out* the resistance.

The galvanometer is very simple in construction, consisting as it does of a single coil of wire, in which is pivoted a magnetic needle with an aluminium pointer

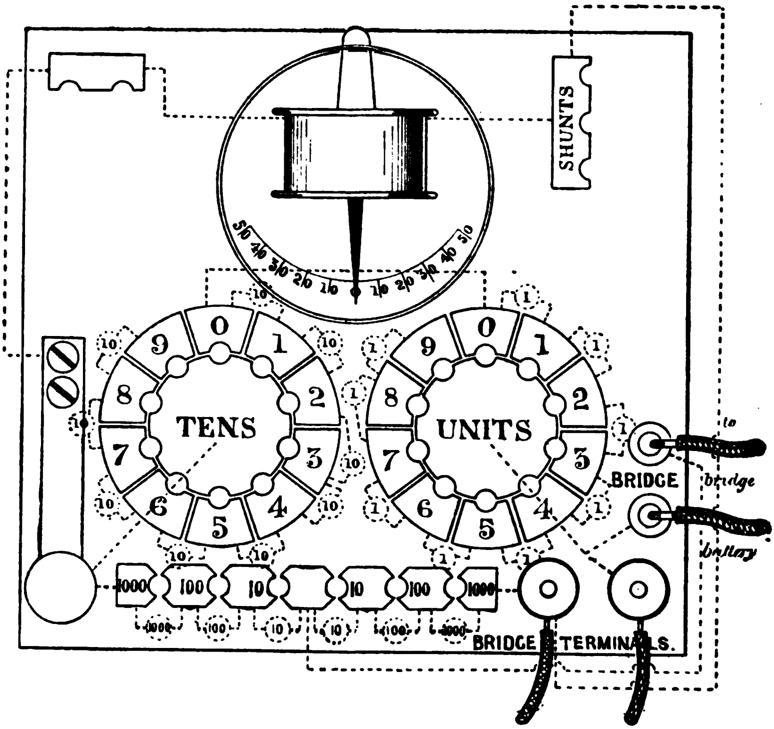


Fig. 109. Silvertown Testing Set. (Conductor Resistance.)

fixed at right angles. A controlling magnet fitted on the left-hand side of the box (Fig. 107), serves to increase or diminish the sensitiveness of the galvano-

meter. When the magnet's N. pole is uppermost, the galv. will be most sensitive; if the S. pole is at the top, the deflection of the needle due to any given current will be diminished to nearly one-half.

Fig. 109 is a repetition of Fig. 108, except that all those portions of the apparatus not used for the first test (conductor resistance) are left out. The "bridge battery" is connected to the plug holes marked BRIDGE, and in lieu of a battery key either of these plugs must be inserted or withdrawn. The resistance to be measured is connected with the terminals marked BRIDGE TERMINALS. The diagram is, in fact, that of a Wheatstone bridge, and should be carefully compared with Figs. 89 and 92. The straight row of resistances are the ratio arms of the bridge (§ 112), the two dials are resistances in *R* (Fig. 89), and the key is the galvanometer key *GK*. The method of making the test will be fully understood from what was said in § 112.

Fig. 110 shows the connections for the insulation resistance test, and it will be noticed that the dial resistances are not used, and the ratio arms are plugged up. The "insulation battery" is connected with the plug holes marked INSUL^{N}., the terminal to the left of the galvanometer (marked INSUL^{N}.) is connected with the conductor whose insulation is to be measured, the other end and all branches from that conductor being insulated. The terminal marked EARTH is joined to Earth (such as the nearest water pipe), or with the sheathing or armouring of the cable under test, if there is any. The galvanometer may be shunted with either of three

shunts; and according to the position of the plug, $\frac{1}{5}$th, $\frac{1}{20}$th, or $\frac{1}{100}$th part of the current only passes through the galvanometer. The reason for using shunts was ex-

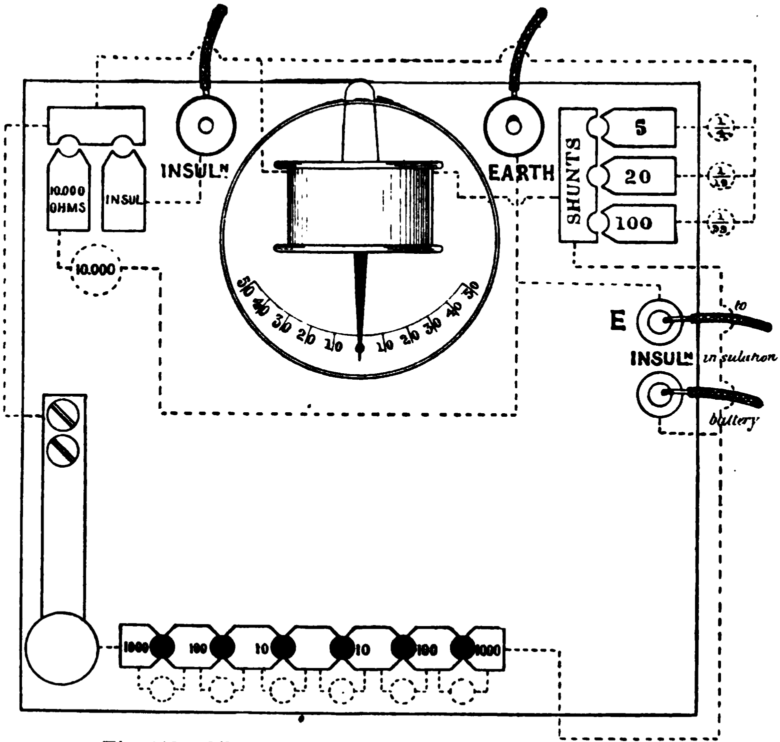


Fig. 110. Silvertown Testing Set. (Insulation Resistance.)

plained in § 110. If the diagram (Fig. 110) is carefully studied, or better still, redrawn in another form so as to include both battery, cable, and Earth, the reader will

easily follow the method of making the test. First of all, it should be noticed that the key now forms a short circuiting key to the galvanometer, and is not in either of the two main circuits which start from the left-hand plug block. By means of the key the oscillations of the needle may be checked. According as the plug is placed in the plug block the current flows:—(i.) through galvanometer, into cable, across insulation, and *viâ* sheathing or E. back to battery: or (ii.) through galvanometer, resistance coil of 10,000ω, and back to battery.

The test thus consists in comparing the deflection which the galvanometer gives when the battery is joined up with the insulation in circuit, with the deflection given when the known resistance of 10,000ω is in circuit with the same battery. The readings on the specially constructed scale of the galvanometer being proportional to the currents passing through, it follows that the deflections are inversely proportional to the resistances.

Thus:—

R. through cable insulation : 10,000ω : : deflec. through 10,000ω. : deflec. through cable insulation.

The use of the galvanometer shunts (which is nearly always necessary,) makes the calculations more complicated than this; but enough has been said to give the reader some idea of the use of the apparatus.

In some forms of portable testing set, all loose plugs are dispensed with, lever switches being used instead.

124. THE OHMMETER. An ohmmeter is an instru-

ment for directly measuring resistances by the indications of a pointer moving over a dial; and may be used for resistances up to 50 Ω or more, according to the winding of the instrument. An ohmmeter indicates the ratio or proportion between the P.D. at the ends of

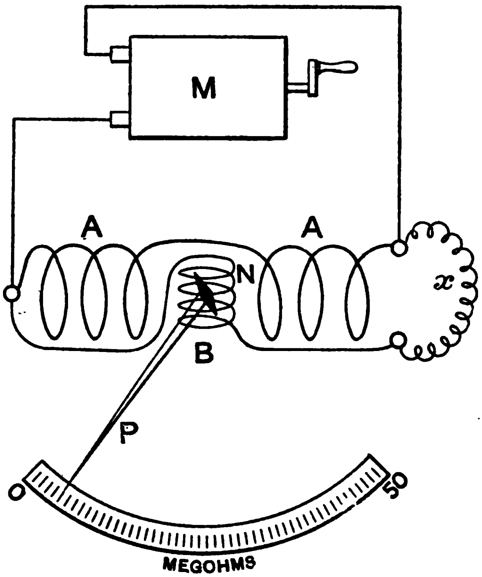


Fig. 111. Diagram of the Ohmmeter.

a conductor, and the current passing through that conductor, and thus gives the resistance in ohms; for the ratio $\frac{\text{volts}}{\text{amperes}} = \text{ohms}$.

When used as a portable instrument, as in Ever-

shed's Testing Set for the measurement of insulation resistance (Fig. 112), it is joined up direct to the circuit, in conjunction with a magneto machine (or "generator") giving an E.M.F. of from 100 to 1,000 volts, and the resistance is indicated on a dial. The "generators" are wound for E.M.Fs. of 100, 200, 500, or 1,000 volts as required. A high E.M.F. is necessary, as it is quite impossible to detect faults in the insulating cover of a wire if a low pressure is used. Fig. 111 illustrates diagrammatically the principles of the instrument, and Fig. 112 shows the apparatus itself.

The construction and action of the instrument are as follows. Two fixed coils *A A* (Fig. 111) are joined up in series, and between them is fixed a third coil *B*, with its axis at right angles to the axis of the coils *A A*. Inside *B* is pivoted a double soft iron needle *N* carrying the pointer *P*. Were the needle *N* acted upon by the coils *A A* alone, it would place itself with its length parallel with the axis of these coils; while if the coil *B* alone acted upon it, it would take up a position at right angles with the axis of *A A*, *i.e.* parallel with the axis of *B*. For any piece of magnetisable metal, free to move, will set itself with its greatest length parallel with the lines of any magnetic field in which it is placed. When both coils act together, the needle takes up an intermediate position which depends upon the resultant effect of the two fields of *A A* and *B*, and is consequently proportional to the ratio between the strengths of these fields. x is the unknown resistance. If this be very great, very little or no current will pass

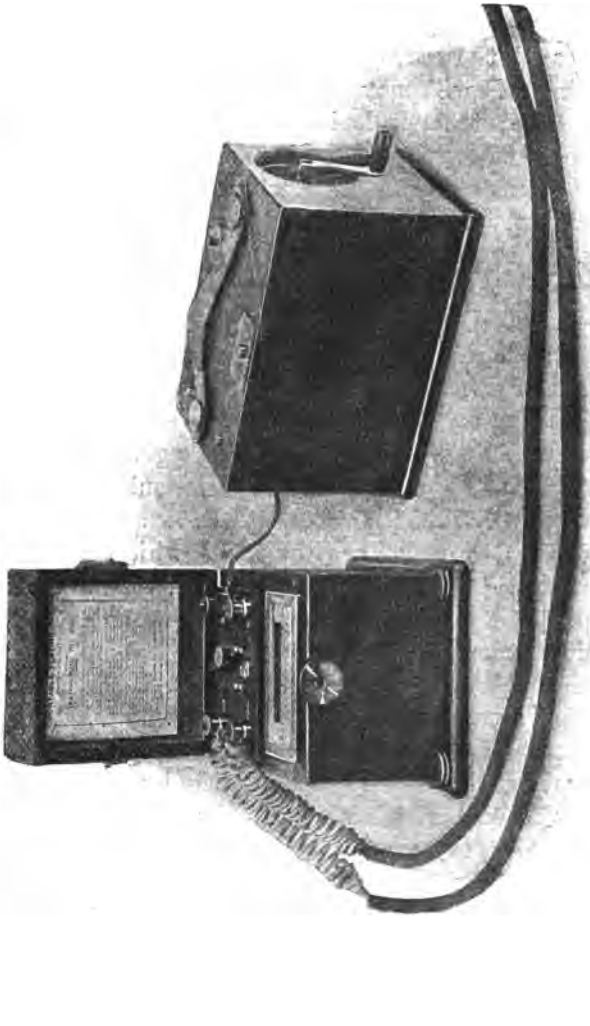


Fig. 112.– Ohmmeter and Generator.

through the coil *B*, and that through the coils *A A* will keep *N* and *P* at the right-hand end of the scale. If x is decreased, the current through *B* is increased, and the pointer *P* will move back over the scale to such a position that the needle is in equilibrium under the forces exerted by the coils *A A* and *B*.

M is the magneto-machine which furnishes the testing current.

Fig. 107 represents the actual instruments joined up to measure the insulation resistance between the + and − leads of a circuit. The ohmmeter is made in three standard sizes reading up to 5, 10, and 60 megohms respectively. For other than insulation resistance tests, smaller instruments reading up to about 100 ohms are made, the generator giving 10 volts.

All that is necessary in testing the insulation resistance of any circuit, is to connect the + and − mains (the insulation resistance between which is to be measured) to the terminals of the ohmmeter, and turn the handle of the generator, when the needle of the former at once points to the number of ohms representing the insulation resistance.

* 125. Measurement of E. M. F. (or P. D.) and Current. In electrical engineering work, electrical pressure is generally measured directly by instruments called *voltmeters*, which are inserted as shunts between the two points of a circuit the P.D. or pressure between which it is desired to measure. A voltmeter must always have a comparatively high resistance, so that the total resistance, and consequently the P.D. or fall

in volts between the points of the circuit tested, may not be altered. For this reason, the coils of some instruments are wound with wire of high specific resistance, such as platinoid or german silver.

In many cases instruments of the same type may be used either as *voltmeters* or *ammeters*; the only difference being that in the first case the coil must be long and thin, and in the latter short and thick. Strictly speaking, all voltmeters which allow electricity to pass through them are also ammeters, for they measure the current proportional to the volts pressure at their terminals. Such currents are of course, very small, usually some fraction of an ampere. The term ammeter is therefore generally applied to instruments of low internal resistance, otherwise their introduction into the circuit would reduce the current it was desired to measure.

For the measurement of very large currents, ammeters are sometimes joined up as a shunt to a known low resistance inserted in the main circuit. The current passing through the instrument is then only a fraction of the main current, but the scale is graduated to give the actual main current value.

Only a few of the instruments described may be used to measure both alternating and direct E.M.Fs. and currents; the construction of some having to be altered when it is desired to use them for alternating current work (§ 136).

The instruments described in the following paragraphs have not been selected from the many in use

because they are very much better than those which are undescribed, but because it has been the Author's aim to mention those which differ most widely from each other as regards the principle of their action.

* 126. CARDEW VOLTMETER. This apparatus, invented by Major Cardew, belongs to the class known as *hot wire instruments*; for its action depends upon the heating, and consequent elongation, of a wire through

Fig. 113. Cardew Voltmeter (interior).

which the current (proportional to the pressure it is desired to test) passes.

The wire employed is of very fine platinum silver, being ·0025 in. or $2\frac{1}{2}$ mils in diameter (§ 23), and is about four times the length of the tube in which it is enclosed. The tube varies in length from about 18 inches to 3 feet, according to the range of the instrument. This voltmeter, as made by the Edison and Swan United Electric Light Company, is shown in Figs. 113 and 114.

The interior of the case, face downwards, is shown in

Fig. 113; and the whole instrument in Fig. 114, the dial in this case being 5″ in diameter.

One end of the platinum silver wire is fixed to the brass block B, which is connected with one of the terminals of the instrument. Thence the wire passes down the tube, round a grooved pulley, and up again to the small pulley p; from this it passes again down the tube, round a second grooved pulley, and up again, and is finally fastened to the block B', which is connected with the terminal T of the instrument. The small pulley p is made of agate, and is fixed to one end of a

Fig. 114. Cardew Voltmeter (exterior).

brass strip S, which latter is connected by a platinum silver wire W with the adjusting spiral spring $S\,S$. This spring serves to keep the wire taut, and may be adjusted by means of the screw s'. When a current, which is proportional to the P.D. at the terminals of the instrument, passes along the wire, the latter is heated and elongates, and the slack is taken up by the spring SS, so that the brass strip S and wire W are drawn to the right (Fig. 113). This movement is communicated to the pointer of the instrument in the following way. The wire W, before being connected with the spring

SS, passes once round and is fastened to the small pulley *P*, which is fixed upon the same spindle as the toothed wheel *T W*. The latter engages with a pinion fixed on another spindle, which also carries the pointer. Thus it is evident that a very small elongation of the heated wire produces an appreciable deflection of the pointer.

In connection with the terminal opposite to *T* is a vulcanised fibre disc carrying four fuse-wires, placed radially. This can be clearly seen at the top of Fig. 113. The disc is capable of rotation, and when a fuse "goes," owing to too great a current passing through the instrument, a new one may be put in circuit by giving the disc a quarter turn.

It will be seen that the instrument depicted in Fig. 114 reads from 30 to 120 volts. For central station or engine-room use, where the pressure has to be kept at or a little over 100 volts, and it is of advantage to be able to see the voltmeter reading from any part of the room, an instrument reading from 80 to 120 volts, with large figures and divisions on a dial 12½″ in diameter, is supplied.

All hot wire instruments, such as the above or that mentioned in the latter part of § 120, may be used to measure either direct or alternating E.M.Fs. In constructing ammeters on the hot wire principle, care must be taken to keep the resistance low (§ 148).

127. AYRTON AND PERRY'S TWISTED-STRIP VOLTMETERS AND AMMETERS. Although these instruments are perhaps rather too delicate for ordinary use, the principle of their action is of interest.

T S is a vertical twisted metal strip, with a pointer *P* fixed midway between its ends. The current to be measured passes down this strip and heats it. The strip consequently untwists, and the pointer moves round in a horizontal plane over the scale *S*. The

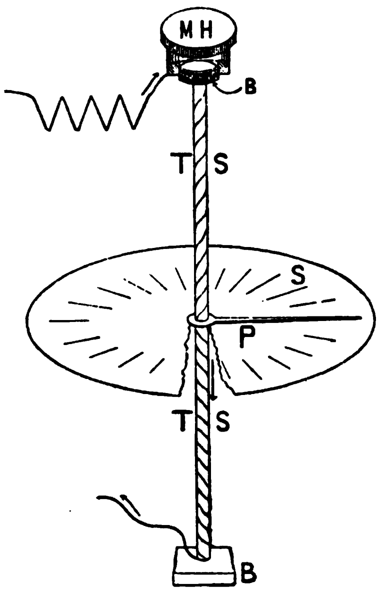


Fig. 115. Principle of Twisted-Strip Instrument.

twisted strip is fixed at its ends to the blocks *B* and *B'*. The upper block *B* is tapped, and by means of the milled head *MH*, may be slightly raised or lowered without turning, and the pointer thus adjusted to zero.

* 128. The Cell Tester. This instrument, also on

the hot wire principle, is constructed for measuring small P.Ds. from 1 to 4 or 5 volts, and is thus very convenient for testing secondary cells, hence its name. The construction of the particular form of the instru-

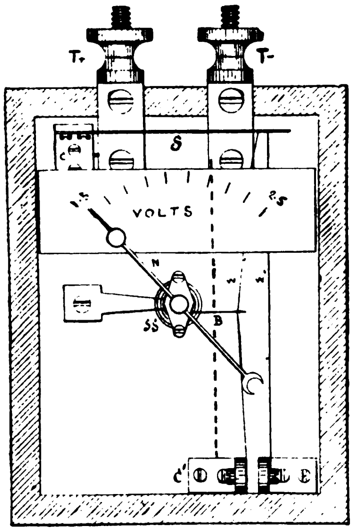


Fig. 116. Cell Tester (interior).

ment known as the Holden, Drake, and Gorham cell tester is shown in Figs. 116 and 117.

The spring *S* (at the top of the instrument) fixed at one end to the anglepiece *C*, carries at its other extremity two fine wires, *W W'*, of the same size and material, which are stretched, as shown, from the top to the bottom of the instrument. Only one of these (*W*)

carries the current, the other being insulated. Under ordinary circumstances the needle N is unaffected by variations of temperature, as both wires expand alike. But the moment W is heated by the passage of the current, it expands more than W', and consequently

Fig. 117. Cell Tester (exterior).

has a certain amount of sag, as the spring S is still held down by the wire W'. A hair-spring SS fixed to the axle of the instrument tends to turn the needle round over the scale, but is prevented from so doing by the bar B fixed to the wire W. Directly W is heated, the sag is taken up by B and SS, and its amount indicated

by the movement of *N*. The needle is adjusted to zero by means of the thumbscrew beneath the scale (Fig. 117). The passage of the current is as follows: from $T+$ to C, along S, down W to C', and thence to $T-$. The cell tester shown reads up to 2·5 volts.

Fig. 118 shows about $\frac{1}{8}$th full size a *contact rod*, which is used for testing secondary cells in conjunction with the above instrument. The lugs *L L* are connected with the terminals of the cell tester, which

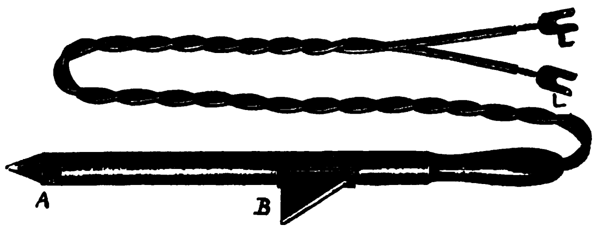


Fig. 118. Contact Rod.

the battery attendant carries in one hand, the contact rod being in the other. The wires attached to the rod terminate at the metal blocks *A* and *B*, which enable very efficient contact to be made with the lugs of each separate cell.

* 129. KELVIN ELECTROSTATIC VOLTMETER. The class of instruments of which Lord Kelvin's *vertical scale electrostatic voltmeter* (Fig. 119) is the simplest example, are peculiarly adapted for measuring high alternating pressures, as there is no complete circuit through them. In the figure, *V* is a light aluminium vane which is supported at its centre on a knife-edge, and is free to move

in a vertical plane midway between the two connected fixed brass strips *B B*. The vane carries at its upper end a light aluminium pointer *P*, and to its lower end may be hung small weights *W*, which tend to keep it in an upright position. The fixed plates and the movable vane are connected with two terminals fixed on one side

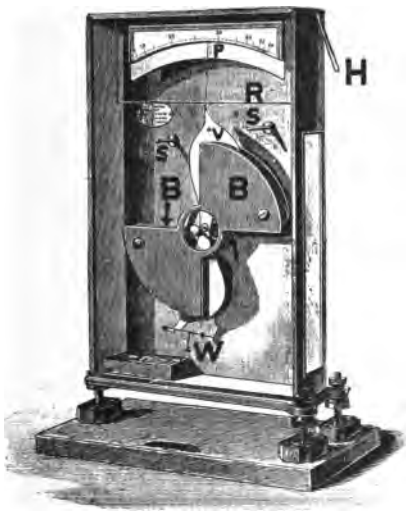


Fig. 119. Lord Kelvin's Vertical Electrostatic Voltmeter.

of the case. In order to save time by checking the oscillations of the vane, a fine horizontal insulated rod *R*, actuated by the handle *H*, may be brought forward so that the pointer rubs against it. The stops *S S* limit the range of movement of *V*, and prevent damage to the pointer.

When the instrument is joined up to any two points of a circuit, the P.D. between which it is desired to measure, the difference of potentials causes the fixed and movable plates to mutually attract each other, and as a consequence the vane moves in between the fixed plates. The amount of this movement, and therefore the P.D. to be measured, is indicated by the pointer on the scale. Such an instrument will measure from 500 up to 20,000 volts.

130. SWINBURNE'S ELECTROSTATIC VOLTMETER (HOLT'S PATENT.) Fig. 120 shows a complete instrument with open-faced dial, a plan with dial removed being given in Fig. 120A, and a side-sectional view in Fig. 120B. Fig. 120C gives a separate sketch of the vanes and pointer. Q_1, Q_2, Q_3, and Q_4 (Fig. 120A) are four quadrant-shaped brass cases, the form of which will be more clearly seen from Fig. 120B, where a section of Q_1 and Q_3 is given: the top surface of the quadrants can also be seen in Fig. 120. Q_1 and Q_3 are connected together, as are also Q_2 and Q_4, the position of the connecting brass strips being shown dotted at w and w' (Fig. 120A). Q_1 is connected with one of the terminals, and Q_2 with the other, the connection being through fine copper fuse wires enclosed in glass tubes. In the event of any sparking or arcing taking place between the differently charged parts of the instrument, the resulting current fuses these wires, and any short-circuiting of the mains to which it may be connected, as well as damage to the instrument, is prevented. These fuses are on the outside of the case at the back, and are thus easily got

at for renewal. One of them is shown at *F* (Fig. 120B), their position being shown dotted at *F* and *F′* in Fig. 120A. The parts of the instrument are mounted on a thick ebonite base (shown black in Fig. 120B), and the

Fig. 120. Swinburne's Electrostatic Voltmeter.

surface between the quadrants is corrugated, as at *C*, *C*, *C*, *C*, (Fig. 120A), to increase the insulation, and prevent leakage between the oppositely charged quadrants. For this purpose also the terminals are very highly insu-

lated, one being shown at T (Fig. 120B): the terminal shank is enclosed in an ebonite tube $E\,T$, and its inner end provided with an ebonite cap $E\,C$. The position of the terminals and their ebonite caps is shown at

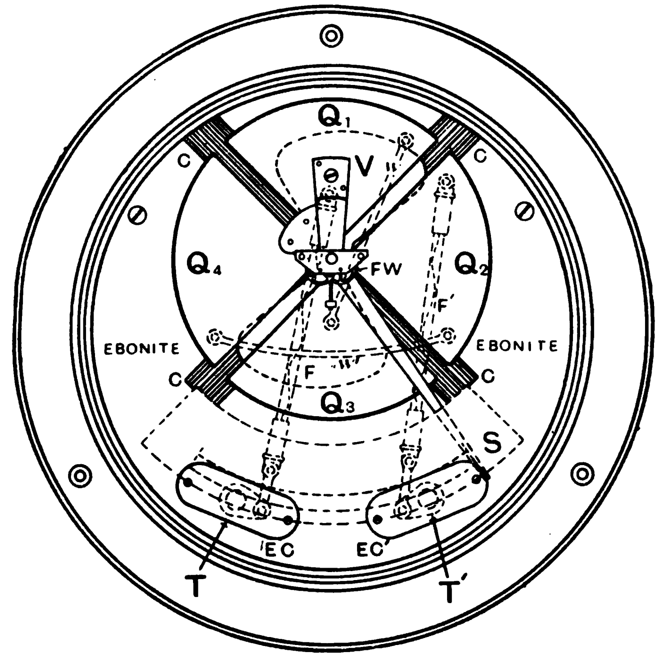


Fig. 120A. Swinburne's Electrostatic Voltmeter (plan) (about ⅓rd real size).

T and T', $E\,C$ and EC' in Fig. 120A. The pointer P and vanes (of which there are two) V, V', (Fig. 120B), are mounted on a light steel spindle resting on *friction*

wheels F W (Figs. 120A and B): these can also be seen in Fig. 120. This kind of bearing, which enables the spindle to turn very easily and freely, is as follows:—two small wheels with smooth sharp edges are mounted

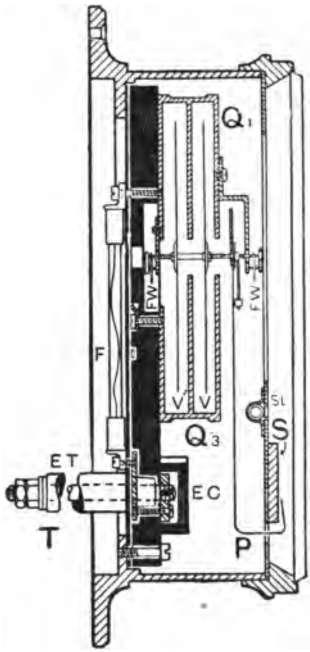


Fig. 120B. Swinburne's Electrostatic Voltmeter (side section).

side by side in jewelled or highly-finished bearings, so that they overlap, but do not touch; the end of the spindle rests between and on their top edges. The front vane, pointer, and counterweight are shown in

Fig. 120c. The vanes and pointer are of aluminium, and to decrease their momentum and render the instrument more dead beat, the former are perforated: their peculiar shape will also be noticed. *P* projects round in front of the scale *S*, as shown in Fig. 120B: the position of *S* is shown dotted in Fig. 120A. It is obviously important that the instrument be set up perfectly level, and for that purpose a spirit level *SL*

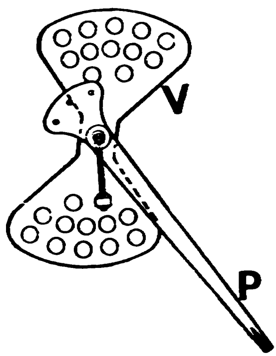


Fig. 120c. Swinburne's Electrostatic Voltmeter. (Pointer and Vanes.)

(Fig. 120B) is provided: *SL* can also be seen in Fig. 120.

The instrument is adapted to the measurement of either direct or alternating pressures, and is made in various ranges—800 to 1,600; 1,400 to 2,600; and 1,800 to 3,200 volts being the ordinary. It can, however, be made to read up to 8,000 volts; and in a different form to 50,000 volts.

Its action is as follows:—the vanes are in connection through the spindle and bearings with the quadrant Q_1, as shown in Fig. 120B, and thus Q_1, Q_3 and the vanes are in connection with one terminal T of the circuit, Q_2 and Q_4 being joined to the other T'. The zero position of the vanes is shown dotted in Fig. 120A; and it will there be seen that they project slightly from the enclosing quadrants. Suppose the terminals T and T' (Fig. 120A) are connected respectively with the + and − points in a circuit, the pressure between which it is desired to measure: Q_1, Q_3 and the vanes will become +ly electrified, and Q_2 and Q_4 −ly electrified; the vanes will consequently be repelled by Q_1 and Q_3 and attracted by Q_2 and Q_4, against the force of gravity acting on the counterweight; the projection of the vanes when in the zero position will cause them to move round in a clock-wise direction, and the pointer will move from right to left. The same reasoning applies with an alternating pressure, it being remembered that though the electrification is rapidly alternating, the vanes Q_1 and Q_3 are always similar in electrification, and opposite to Q_2 and Q_4.

131. THE MULTICELLULAR ELECTROSTATIC VOLTMETER. Fig. 121 shows the *engine-room pattern multicellular voltmeter*, designed by Lord Kelvin. There are a number of vanes fixed to a vertical spindle. The top end of the spindle is suspended by a small spring and a fine platinum-iridium wire from the top of the instrument, while its lower end terminates in a disc turning in an oil dash pot. The movements of the instrument

are thus rendered dead beat. The upper end of the row of vanes carries a light pointer, which is bent over in front of the scale.

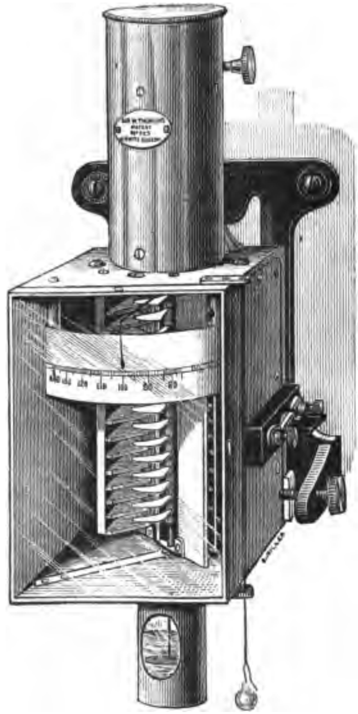


Fig. 121. Multicellular Voltmeter.

Equal in number with the vanes are a set of cells formed of strips corresponding with *B B* in the illustration of the vertical electrostatic voltmeter. (Fig. 119.)

Because of the number of vanes and cells, this instrument reads much lower than the single vane voltmeter, its range being from 40 volts upwards.

132. Ayrton and Mather's Electrostatic Voltmeter. The action of this instrument, in common with that of the other electrostatic voltmeters described in previous paragraphs, depends on the electrostatic attraction set up between two conductors connected with the two points of the circuit whose P.D. is to be measured. The fixed and movable portions of the Ayrton and Mather instrument are shown diagrammatically in

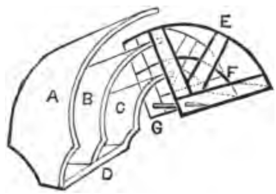


Fig. 122. Ayrton & Mather's Electrostatic Voltmeter.
(Diagram of fixed and moving parts.)

Fig. 122. The three curved plates, *A*, *B* and *C*, which are firmly fixed to the plate *D*, constitute the fixed part; and *E F G* the movable part. *E* and *F* are curved aluminium plates fixed to the staff or axle *G*. The controlling force is gravity, a small weight (not shown) being attached to an arm on the axle. *A B C* and *E F* being respectively connected with the points of the circuit to be tested, it must be evident that the greater the P.D. the greater will be the force with which *E F* is drawn over to embrace *B C*, the counter-

poise tending all the while to pull $E F$ back to the zero position. This force is, in fact, proportional to the square of the pressure. A pointer attached to the front end of G, indicates the amount of movement of $E F$ on the scale in front of the instrument.

The latest form of the moving part is shown in Fig.

Fig. 123. Ayrton & Mather's Electrostatic Voltmeter.

124: the curved aluminium plates or vanes are practically the same as before, but an addition has been made in order to "damp" or retard the oscillations of the moving part, and make it come to rest more quickly, *i.e.*, render it more dead beat. This is effected by mounting a strong horseshoe permanent magnet on the frame which carries the pointer and vanes, and

fixing to the movable part a flat piece of copper. When the vanes are deflected, the copper plate moves between the poles of the magnet, and the eddy currents set up therein tend to retard its motion in accordance with Lenz's law, though the ultimate position which the needle will take up is, of course, not affected.

Fig 124. Ayrton & Mather's Electrostatic Voltmeter. (Moving vanes and damping device.)

The complete instrument is shown in Fig. 123. The small thumb-screw at the top operates a pinion gearing into a rack fixed to a second pointer, which may be thereby adjusted to any part of the scale, to permanently indi-

cate the required pressure: any variation of the actual pressure is thus more easily noticed. If this index is turned as far as it will go towards zero, it serves to clamp the other pointer, and thus hold the moving part steady when the instrument is being moved.

A voltmeter for high-pressure work must be highly insulated, to prevent accident to persons using the instrument. In the present case, all the exterior parts are insulated from the circuit, so that a person handling the apparatus cannot receive a shock

Fuses enclosed in removable glass tubes with brass caps are provided; they slip into ebonite tubes projecting into the instrument, and so make contact with the working parts.

The terminals are embedded in a block of ebonite hinged to the case, and are fitted with ebonite-headed screws. Thus no metal parts are exposed to the touch.

Fig. 123 shows this terminal block and terminals, and also a screw (between the terminals) which is used for fixing the block. The latter also carries ebonite encased caps which, when pushed home, connect the terminals with the protruding ends of the fuse tubes. In the position shown, the block has been moved so as to break contact with the fuse tubes and instrument. It is thus evident that contact may be broken between the terminals and the instrument, and fresh fuses inserted, without disconnecting the outer wires.

A spark gap is provided inside the instrument, and adjusted to allow the passage of a spark should the potential rise to double the working pressure. This

prevents sparking between the working parts, which are tested to more than double the normal pressure. On a spark passing at the gap, the fuses are blown, thus cutting the instrument out of circuit.

* 133. SWINBURNE'S "N" TYPE VOLTMETERS AND AMMETERS. These instruments consist of a pair of astatic needles, and a current-carrying coil: their principle of action is thus the same as that of the astatic detector described in § 118. They are clearly only adapted for direct-current work, but by reason of their construction, are claimed to be unaffected by neighbouring fields, and to be cheap.

The interior of a voltmeter is shown in Fig. 125, the exterior being very similar to that of other instruments. BF is a brass skeleton frame on which is wound a coil of fine wire C of about 800ω resistance: another coil R of platinoid wire, and about $3{,}200\omega$ resistance, is joined in series with C, and the two are connected with the terminals T and T'. The use of R is to reduce the current passing through the instrument, and to minimise any error due to the current heating the coil and increasing its resistance: for if the deflecting coil of a voltmeter heats and increases in resistance, the current passing through it, due to a given pressure, will be reduced, and the coil will exercise less deflective force than it ought, thus giving a wrong reading. The turns of the coil are opened out at O, to enable the needles to be put in place. The latter, one of which (N) can be seen in the figure, are of thin sheet steel carefully magnetised, and the poles being close together, they

are little affected by external fields. The flatness of the needles and the closeness together of the poles (giving a nearly closed magnetic circuit,) is the special feature of this instrument. The needles and pointer *P*, as

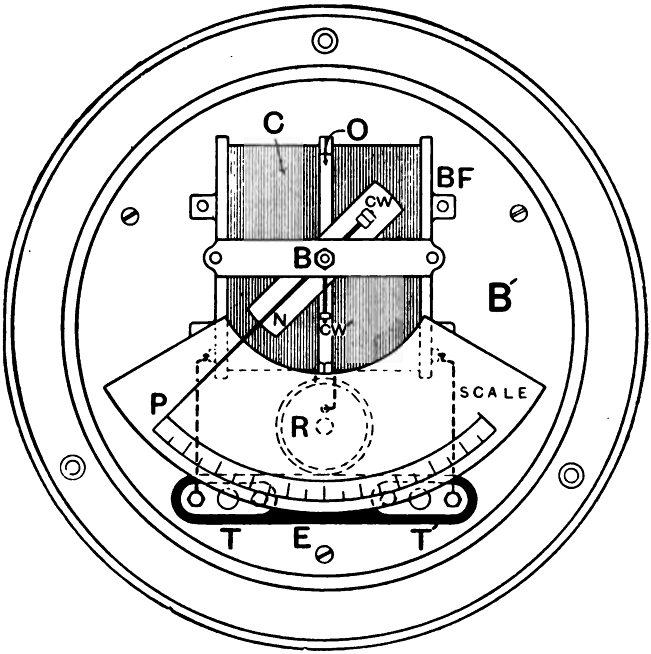


Fig. 125. Swinburne's "N" type Voltmeter (interior, ½ real size).

well as two counterweights *C W*, *C W′* are fixed to a steel spindle mounted in bearings, one of which (*B*) can be seen on the front of the coil. *C W* is used to balance the needles and pointer, while altering *C W′*

increases or diminishes the sensitiveness of the apparatus.

The parts are mounted on a sheet-iron base *B′*, and the terminals on an ebonite block *E* shown black.

Voltmeters of this type are generally constructed for ranges up to 100 or so volts, but can of course be made to read to higher values.

Fig. 125A shows an ammeter coil for this type of

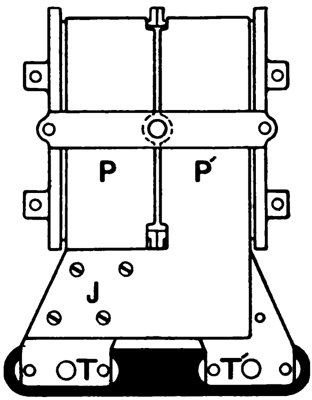


Fig. 125A Coil of Swinburne's "N" type Ammeter (½ real size).

instrument. The winding consists of a single turn of copper strip, carefully insulated from the brass frame. It is in two pieces *P* and *P′* joined in parallel; one joint is shown at *J*, the other being below. *T* and *T′* are the terminals. For heavy currents the instrument is arranged as a shunt across a low resistance in the main circuit, so that the thick main leads need not be led to and from the ammeter. This is somewhat

but not strictly similar to the potentiometer method of measuring current, and should be carefully thought out by the student. (§§ 115, 125.)

134. SWINBURNE'S "U" OR INDUCTOR TYPE INSTRUMENTS. This class of instrument for alternating-current work, which may be fitted either as a voltmeter, am-

Fig. 126. Swinburne's Inductor type Voltmeter.

meter, or wattmeter, is unique in principle; and though not complicated in construction, its action is somewhat difficult to explain clearly. *IC* (Figs. 126A and 126B) is a square-shaped iron core built up of thin sheets of soft iron in two pieces, which are bolted together at the joints *J* and *J'*; the larger sheets having a projecting piece *P*. These sheets, or stampings, are insulated

from each other with thin paper, to prevent the setting up of eddy currents. A closed magnetic circuit is thus provided for the two coils C_1 and C_2, which are of copper wire and joined in series · while the magnetic

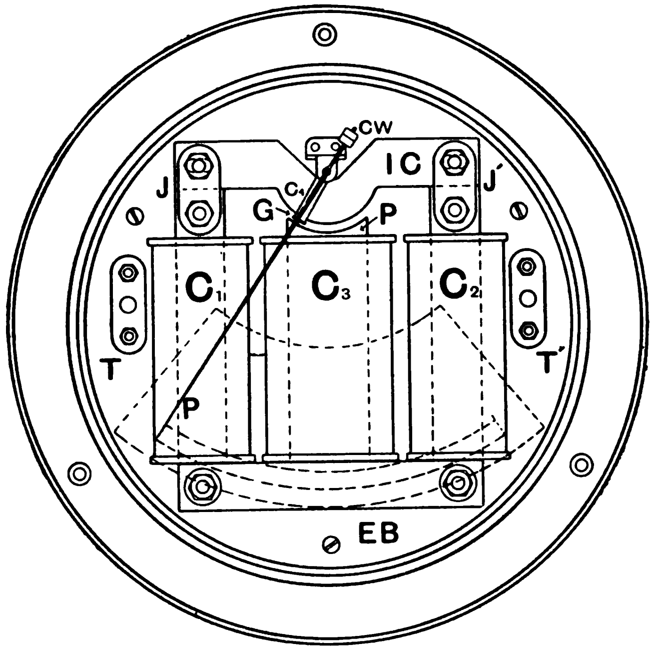


Fig. 126A. Swinburne's Inductor type Instrument (interior, about ½ real size)

flux due to the third coil C_3 completes its circuit across the air gap G. C_4 is a coil of a single turn, three sides of which are made of copper strip, while the fourth, which moves in the field gap G, is of manganin, to

retard the setting up of induced currents in it. C_4 embraces the iron core IC, and is fixed to an arbor or spindle, together with a pointer P and counterweight $C\,W$.

The fixing of the parts to the ebonite base $E\,B$ is clearly shown in Fig. 126B. The terminals T and T' are like those described in § 130, but they are unprovided with ebonite caps when the instrument is only to be used for low pressures.

The action of the instrument is briefly as follows:—the passage of an alternating current through C_1 and C_2 sets up a magnetic flux in the core which induces an alternating current in C_4.[1] C_4 being movable, and one side of it being in a correspondingly alternating field due to C_3, that side will travel along the air gap G, and C_4 and P will be rotated.

C_4 is the same whether the instrument be used as a voltmeter, ammeter, or wattmeter; but the connection and winding of C_1, C_2, and C_3 differ in these various cases.

In a voltmeter, C_1 and C_2 are of copper wire (about ·02 inches diameter), connected in series to the terminals, and of a low resistance. C_3 is of fine german silver or manganin wire wound to a high resistance, and joined as a shunt to the terminals T and T'.

In an ammeter, the connections are just the same, but C_1, C_2, and C_3 are wound with much thicker wire.

In a wattmeter, C_3 has a copper winding of low

[1] See Chap. XVI., Vol. II.

resistance, and is joined up in the main circuit; while C_1 and C_2 are wound the same as in a voltmeter and connected in series with two separate terminals. As before mentioned, the main current is sent through C_3,

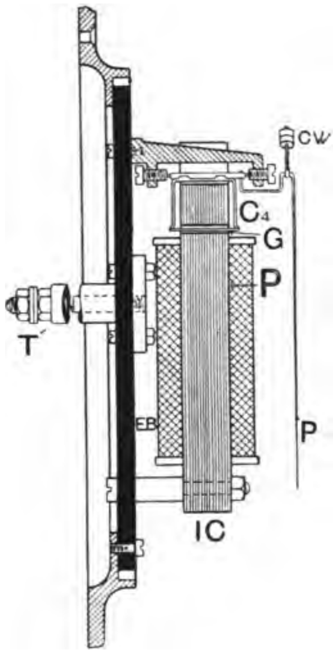


Fig. 126B. Swinburne's Inductor type Instrument (side sectional elevation).

while C_1 and C_2 are connected as a shunt to that portion of the circuit whose power is to be measured.

The action of these instruments will be better

understood when the theory of alternating currents has been investigated (Vol. II.).

§ 125. [illegible]'s Gravity Voltmeters and Ammeters. The working parts of these instruments have recently been improved, the principle of their action however, being very much the same as before. The complete instrument is shown in Fig. 127. If the

Fig. 127. [illegible]'s Voltmeter.

[illegible] and the three small screws [illegible] be undone, the [illegible] may be withdrawn from [illegible] technically called the [illegible] where N is the needle [illegible] bearings, C the [illegible] in Fig. 127), A [illegible]

the soft iron armature fixed to the axle, *P* the brass case or "plug" which is open at *O*, and *S* a peculiarly-shaped soft iron sleeve which fits on to *P*, but is shown apart and in perspective for the sake of clearness. The armature *A* is more clearly shown in Fig. 129, together with the axle, *N*, and *C*. A section across the "plug," showing the sheath *S* in place, and its

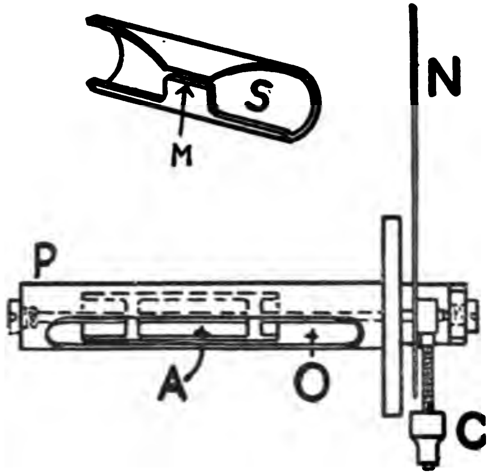


Fig. 128. Evershed's Voltmeter. ("Plug.")

position relative to the armature *A* when the latter is at zero, is given in Fig. 130; and by the help of this and the perspective view of *S* in Fig. 128, the action of the instrument may be explained. *S* offers a variable path to the lines of force due to the current, which pass from end to end of the coil; and at and about the point *M* there is more or less free magnetism: to this

region *A* is attracted against the gravitating force of *C*. The zero position of *A* is shown in Fig. 130, *C* (represented by a dotted line) being heavier than *A*. The amount of the attraction between *A* and *M* depends, of course, on the current passing through the coil.

Fig. 131 gives a plan of an ammeter, with the cover,

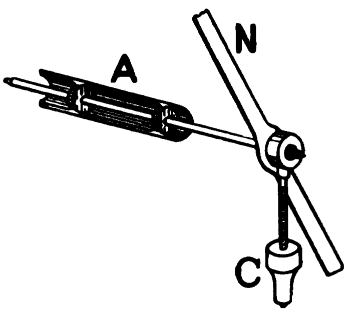


Fig. 129 Evershed's Voltmeter. (Armature and Needle.)

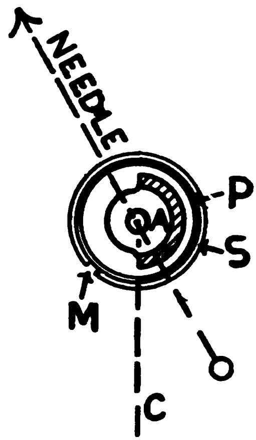


Fig. 130. Evershed's Voltmeter. (Section across "Plug.")

"plug," and dial removed. The coil *C* (which, in the particular instrument inspected, had 8 turns,) is of thick insulated cable whose ends are soldered in the terminal sockets *T S*, *T S*, which pass through the base, but are insulated therefrom by ebonite (shown black). The hollow of the coil *h* is where the plug is inserted.

136. Modification of Instruments for Alternate Current Work. Ammeters and voltmeters constructed for use with continuous currents and E.M.Fs., generally have to be modified in some way or other if it is required to use them for alternating currents or E.M.Fs.

The Evershed instruments are modified for alternate

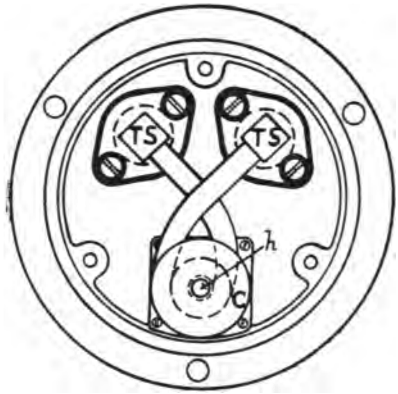


Fig. 131. Evershed's Ammeter. (Coil and Base.)

current work as follows. The ammeters are constructed with a shunt to the working coil, which with a continuous current would shunt off about 5 % of the current. The shunt is made like a choking coil, that is, it has inductance; and when the ammeter is used to measure alternate currents, only about 2 % of the current is shunted, leaving an additional 3 % for the working coil, and so raising the readings to the correct effective value.

The voltmeters are corrected for alternate currents in much the same way, though sometimes a diminutive transformer is used, as shown in Fig. 132. The auxiliary circuit has a primary wire *P*, which transforms as many volts into the secondary coil *S* as are required to make up for the back E.M.F. in the working coil of the voltmeter *C*, so that the working coil circuit acts as though it had no self-induction, and the voltmeter then reads the same for alternate as for direct currents.

Besides the above and other compensating arrangements in the actual circuit, coil-cheeks, cores, etc.,

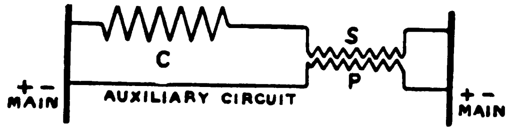


Fig. 132. Winding for Alternating Currents.

must be slotted or laminated to prevent the circulation of eddy currents.

* 137. Ayrton and Perry's Spring Ammeter. In this instrument (Fig. 133) the aluminium pointer *p* is fixed to the top end of a thin, soft iron tube *T*. This tube is fixed at its lower end by a small piece of brass *C*, to the lower end of a spring *S*, the upper end of which is fixed to the milled head *H*. This spring is of a special form (Fig. 134), like a narrow shaving curled up into a cylinder of very small diameter. When the current to be measured passes round the coil *W W* of the instrument, the tube *T* is sucked down,

and the spring being thereby elongated, untwists; the tube and pointer therefore also move round, which movement is indicated by the pointer upon the scale. The small pin *P*, which fits loosely in a hole, tends to

Fig. 133. Ayrton & Perry's Spring Ammeter.

keep the tube central, and so prevents it from touching the sides of the hollow coil. The little compass let into the base of the instrument serves to indicate the direction of the current, by showing the polarity

of the lower end of the coil. The holes seen in the case of the instrument provide for the ventilation of the coil. When wound with thin wire, the instrument will act as a voltmeter.

Fig. 134.
Spring of Ayrton & Perry Instruments. (Enlarged.)

The ammeters have a range from 4 to 600 amperes, and the voltmeters from 15 to 1000 volts, according to the grade of instrument. Portable sets are made with an am- and voltmeter mounted side by side in a box.

Ammeters and voltmeters on this principle, for alternate current work, must have the soft iron tube T' and the bobbin tube and cheeks slit in order to retard the circulation of eddy currents.

* 138. PATERSON AND COOPER'S "PHŒNIX" AMMETER AND VOLTMETER. In these instruments there is a bar electro-

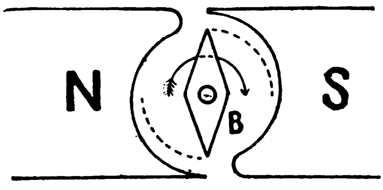


Fig. 135. Needle and Magnet of "Phœnix" Instruments.

magnet, to the poles of which are fixed soft iron pole-

pieces *N S* (Fig. 135). These pole-pieces bend round in front of the coil, and are hollowed out at their extremities. In this space is pivoted a small soft iron needle *B*, to which the pointer is attached. A circular spiral spring of phosphor bronze tends to keep the needle almost at right angles to the magnetic field which is set up between the pole-pieces. When a current passes round the coil of the instrument, this magnetic field moves the needle against the torsion of the spring, tending to turn it parallel with the lines of force of the field. The amount of this turning is indicated by the pointer upon the scale, and is a measure of the strength of current passing through the instrument, or of the P.D. at its terminals. It will be noticed that the inner faces of the pole-pieces are shaped excentrically, and the tendency is for the needle to move round in the direction of the arrow, as in so doing it shortens the air gap between the poles.

138A. Atkinson Ammeter and Voltmeter (Fig. 137A). The moving part of these instruments consists of an hydrometer or float containing a soft iron wire, and weighted at the bottom. This float is placed in a sealed glass tube about two-thirds full of a special liquid. The float is so weighted, that under normal conditions the top of its stem is just out of the liquid; and the containing tube passes so far into a solenoid that when no current is passing the top of the iron wire is just within it. According as the instrument is intended for a voltmeter or an ammeter so this coil is wound either with thin or thick wire. When a

current passes the float is drawn upwards to an extent

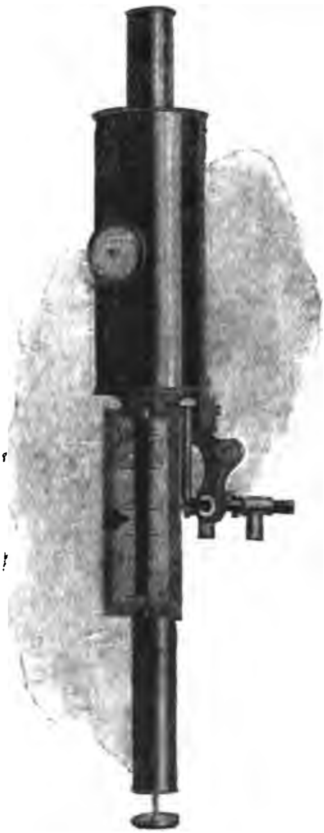


Fig. 137A. Atkinson Ammeter.

proportional to the current, and its position is indicated by a black and white band on the lower and thicker

part of the float. The external appearance of this instrument is indicated in Fig. 137A.

* 139. Simple Gravity Ammeter. The principle of this ammeter will be clearly understood from Fig. 138. Gravity tends to pull the thin, curved soft iron tongue *N* down, while a current passing round the coils *c* sucks it up. The movement of the tongue is shown by the pointer *P*.

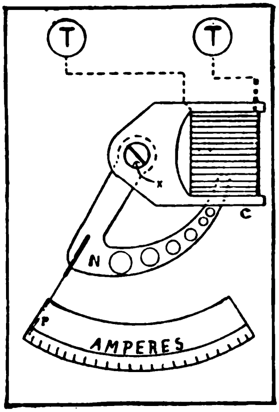


Fig. 138. Simple Gravity Ammeter.

* 140. Holden, Drake, and Gorham Ammeter. The

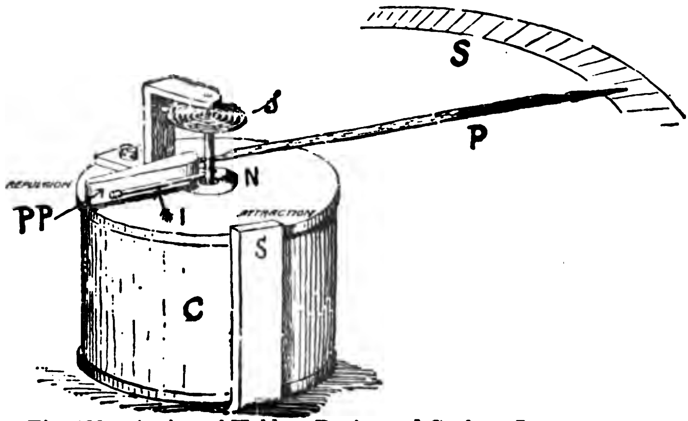


Fig. 139. Action of Holden, Drake, and Gorham Instruments.

working parts of this instrument are shown in Fig.

139, and a complete instrument in Fig. 140. The iron core *N* of the coil *C* has fixed to its upper extremity the peculiarly shaped pole-piece *P P*. The lower end of the core has also a pole-piece, which is brought up the side of the coil and terminates at *S*. The pointer *P* is fixed to an axle which is pivoted between the top

Fig. 140. Holden, Drake, and Gorham Ammeter.

of the core and an angle piece. This axle carries a piece of soft iron *I*, and is governed by a spiral spring *s* which tends to keep *I* against *P P*. *I* is prevented from touching *P P* by means of the small brass collar at its end, for the same reason that the armature of an electric bell is prevented from touching the

magnet poles, by inserting brass pins in the latter: *i.e.*, to prevent the two magnetically sticking together. When a current passes round *C*; *N*, *PP*, and *I* become of north polarity; *I* is consequently repelled by *PP* and attracted by *S*, which is of south polarity, and the arbor and consequently *P* are turned against the

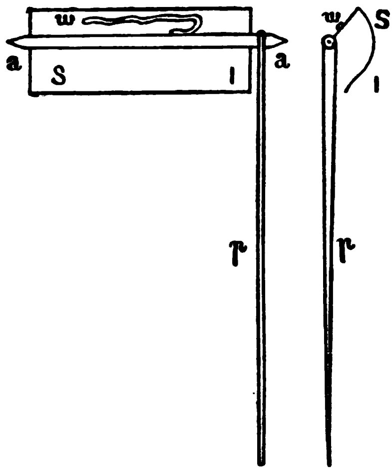


Fig. 141. Armature and Needle of Schuckert Instruments.

torsion of *s* to an amount dependent upon the strength of the current.

A small indicator fitted on the front of the instrument shows in which direction the current is passing.

* 141. Schuckert Voltmeter. The construction and action of the form of Schuckert instrument shown in Fig. 142 is very simple. The moving part

of the apparatus, depicted in Fig. 141, consists of an axle *a a* carrying a curved piece of malleable soft iron *S I*, and provided at one end with a light aluminium pointer *p*. This is pivoted in the coil, but not exactly in the centre. The centre of gravity of

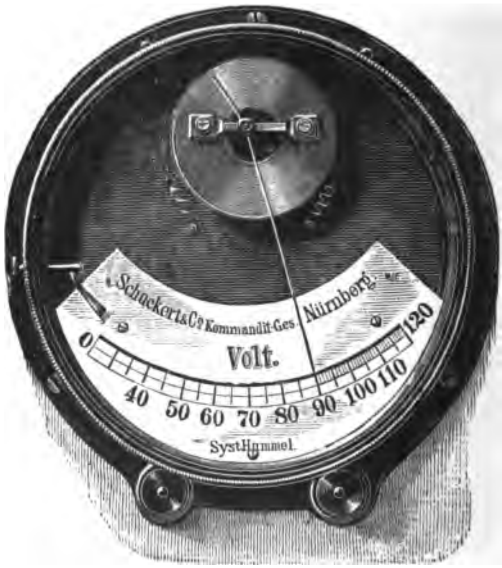


Fig. 142. Shuckert Voltmeter.

the armature is so adjusted by means of the piece of wire *w*, that when no current is flowing round the coil, the index stands at zero on the scale. When a current passes, the iron is drawn into the average strongest part of the field, that is towards the side of

the coil,[1] and the needle is consequently deflected. The whole of the moving part is made very light, it weighing only about $\frac{1}{80}$th of an oz.; there is thus practically no resistance due to friction on the bearings. Fig. 142 shows a complete instrument.

Many other ammeters and voltmeters act on a similar principle to the one just described.

Some forms of Schuckert apparatus are said to be similar in action to the Walsall instruments described in the next paragraph.

* 142. WALSALL INSTRUMENTS. The voltmeters and ammeters constructed by the Walsall Electrical Co. are made in a variety of sizes and forms, the ordinary pattern being somewhat similar to Fig. 143, with the exception of the special contacts and relay there shown.

The working part or "plug" of these instruments, which (as in the case of the Evershed apparatus,) may be easily removed, is shown in perspective in Fig. 144, and in part section in Fig 145. Fixed to the axle a are two armatures A and A', built up of thin pieces of soft sheet iron, in the relative positions shown in Figs. 144 and 145, A' being less than half the length of and much thinner than A. Part of the framework in which the moving part is pivoted consists of a brass tube B,

[1] The internal field of a solenoid midway between its ends is strongest at the centre (axis) of the coil; but towards the ends, where the lines begin to leak out, the field is stronger at the sides than in the centre. Consequently, a piece of iron reaching the whole length of a short coil moves to one side, while a short piece placed in the middle of its length tends to move towards the centre.

which is tightly packed with a number of soft iron wires *W*. The dotted line *d* indicates the hollow of the coil.

The action is as follows:—when a current passes

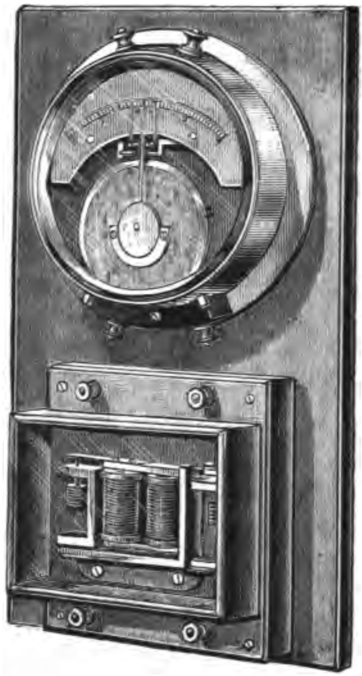


Fig. 143. Walsall Relay Voltmeter.

round the coil, *B* (Fig. 145) repels *A* and the needle moves over to the right. As *A* moves away from *B*, *A′* is brought round towards *B*, against the slight

repulsion which is set up between them; the travel of the needle is thus retarded by this repulsion, as well as by the force of gravity tending to pull *A* down-

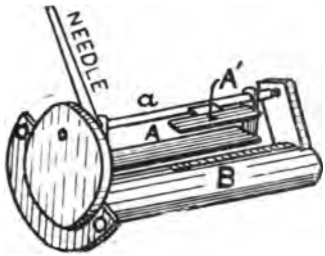


Fig. 144. "Plug" of Walsall Instruments.

wards. This action will be better understood from Fig. 146, where a sectional plan of the coil is given, and *W*, *A*, and *A'* are shown. Suppose a direct current is

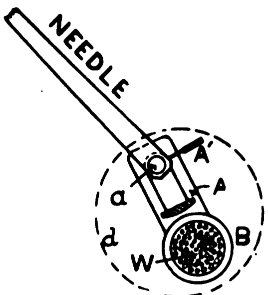


Fig. 145. "Plug" of Walsall Instruments. (Section.)

flowing round the coil, then one end of *W*, *A*, and *A'* will be north, and the other south: thus repulsion will be set up between *N*, *N'*, and *n*; and between *S*, *S'*, and

s: but the repulsion between *W* and *A* will clearly be greater than that between *W* and *A'*, and the needle will move over the scale.

The iron parts being well laminated, the instruments may be used with alternate currents.

Various other instruments act on this same principle.

Fig. 143 shows a special form of *alarm voltmeter*, in which pairs of adjustable contacts are arranged on each side of the needle, these being connected with a relay

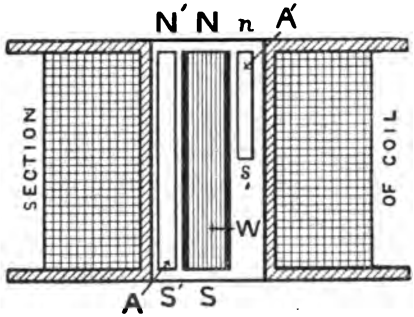


Fig. 146. Action of Walsall Instruments.

below. Any variation of the voltage causes the needle to bring the contacts together on one side or the other, thus operating the relay from one or two cells, the relay being placed in the circuit of an electric bell, or an automatic regulating device.

A useful kind of ammeter, for electric traction work, has vanes fixed upon the working parts, and the whole immersed in a viscous liquid which keeps the needle steady, even though the instrument may be subjected

to a considerable amount of vibration. This form of ammeter, which is intended for direct currents only, differs from most others in that its needle also shows the direction of the current, the needle moving to the right for a current in one direction, and to the left for a current in the other direction.

142A. Davies' Voltmeter (Fig. 146A). This instru-

Fig. 146A. Davies' (Muirhead) Voltmeter.

ment, as made by Muirhead & Co., is similar in principle to the moving-coil galvanometer described in § 120. An elevation and plan of the permanent magnet are given in Fig. 146B, *NN* being the north pole, and *SSS* the south pole. The portion *PM* is the permanent magnet itself, while *PP*, *PP* are soft iron pole-pieces.

A very strong field exists in the air-gap between the poles, and in this field the movable coil is suspended,

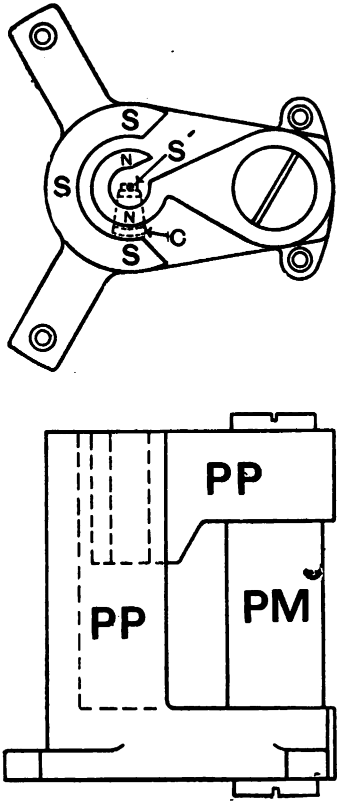


Fig. 146B. Permanent Magnet of Davies' Voltmeter (½ full size).

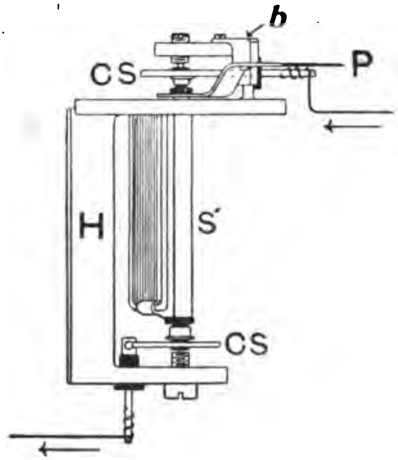
its zero position being shown dotted at *C*. The closeness with which the poles approach, and the way in which

one embraces the other, render the field impervious to any disturbance from outside, so that even if a magnet be laid on the face of the instrument, its indications will be practically unaffected. To further prevent the possibility of any error from such causes, in later instruments the distance between the poles will be still further reduced.

Fig. 146C gives a plan and elevation of the coil, holder *H*, and controlling springs *C S*, *C S*; the appearance of these when in position on the magnet being shewn in Fig. 146A. The coil, of several turns of fine copper wire, is first wound on a former in such a manner that a frame is dispensed with. One side of it is then fixed to an aluminium shaft threaded on to the spindle *S′* (Figs. 146B and C), which also carries an aluminium pointer *P*. The pressure current is led into and out from the coil *viâ* the springs *C S*, *C S*. It will thus be seen that when the coil is in place, one-half only of it is in the field, the other half being inactive; and the current in the coil causes its active half to travel round the field against the torsion of the spiral controlling springs. *b* is a brass piece with two arms, each carrying a pad of cloth; these limit the travel of the needle either way without jar. In order to get sufficient resistance in circuit, a separate fixed coil is joined up in series with the movable coil.

From Fig. 146A it will be seen that the instrument has a very long range, the particular one illustrated reading from 0 to 240 volts: moreover, it should be noticed that the scale divisions are uniform.

The sensitiveness of these instruments is such that



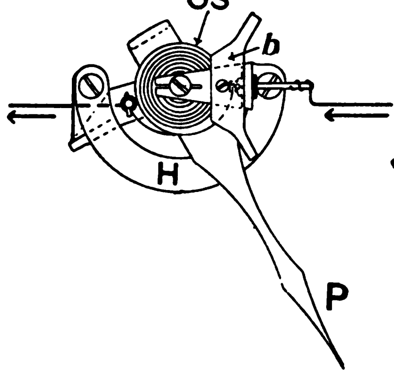


Fig. 146c. Coil of Davies' Voltmeter (½ full size).

they can be made to read accurately from ·01 volts upwards.

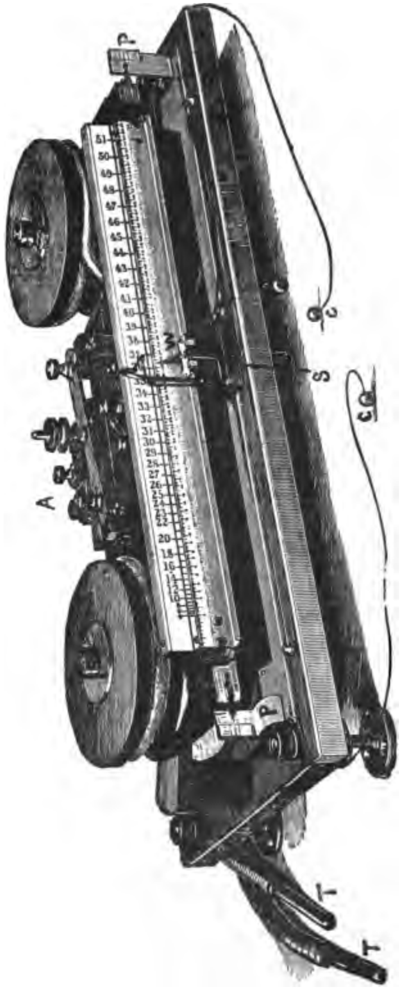
Ammeters on this principle read from ·05 to 3 amperes, or from 1 to 100 amperes and upwards. The moving coil has a few turns of copper wire, and is shunted by a low resistance through which the main current passes (§§ 125, 133).

Obviously these instruments can only be used with direct currents, and care must be taken that the current is sent the right way through. In a gravity form the spiral springs are dispensed with, and the coil is provided with an adjustable counterweight.

142B. Weston Ammeters and Voltmeters. These instruments, of American design, are supplied by Messrs. Elliott Bros. They are very similar in principle to those described in the preceding paragraph. There is a light pivoted coil controlled by spiral springs, and mounted in the field of a magnet which is in some cases permanent, and in others electro.

143. Lord Kelvin's Electric Balances. Lord Kelvin is the inventor of many beautiful and exact instruments for electrical measurements, one of the most remarkable and ingenious classes of which are his *current balances*, which are adapted to the measurement of both direct and alternating currents; while others will also measure volts and watts. They are made in various ranges as follow :—

I. Centi-ampere Balance, measuring from 1 to 100 centi-amperes; *i.e.* from ·01 to 1 ampere.



147. Lord Kelvin's Deka-Ampere Balance.

II. Deci-ampere Balance, measuring from 1 to 100 deci-amperes; *i.e.* from ·1 to 10 amperes.
III. Deka-ampere Balance, measuring from 1 to 100 amperes.
IV. Hekto-ampere Balance, measuring from 6 to 600 amperes.
V. Kilo-ampere Balance, measuring from 100 to 2,500 amperes.
VI. Composite Balance, measuring from ·02 to 500 amperes, and capable of being used also as a voltmeter or as a wattmeter.

Besides these, there are four types of *watt balance* very similar in principle.

Though the working of each type of current balance is the same, the construction varies a good deal, according to the range of the instrument. The one which we shall now briefly describe, and which is shown in Fig. 147, is the deka-ampere balance. The action of the instrument depends, like the electro-dynamometer, upon the mutual forces of attraction and repulsion between movable and fixed portions of an electric circuit (§ 69). In the actual apparatus, the parts of the circuit which thus react on one another are circular. The movable part of the instrument may be compared with a balanced beam, having a horizontal coil fixed at each extremity. Above and below these movable coils are fixed coils; all the coils carrying current in such directions that the beam and movable coils tend to be tilted up on one side, and down on the other.

This arrangement will be more clearly grasped from Fig. 148, where *M C* are the two movable coils, and *F C* the four fixed coils.

The balance arm carrying the movable coils (which is not shown in Fig. 148), carries also a scale *S*, the edge of which is turned up so as to form a rail on which the weight *W* slides. The whole beam is supported on two ligaments *L L'* of fine copper wire,

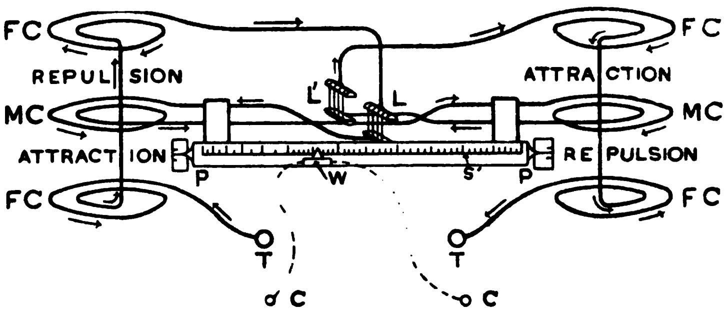


Fig. 148. Diagram of Current Balance.

which also serve to conduct the current into and out from the movable coils.

The current to be measured is passed through the whole of the coils in series, in such a direction that the right-hand movable coil is forced upwards, being repelled by the bottom fixed coil and attracted by the top one; while the left-hand movable coil is drawn downwards, being attracted by the bottom coil and repelled by the top one. As a consequence the beam is tilted over. The sliding weight *W* is then slid

along by the slider S (Fig. 147) until the beam once more lies in a horizontal position, which is seen by observing the little pointers $P P$ shown at each end of the beam. The weight is slid along either way by pulling the cords $C C$. In Fig. 148, for simplicity's sake, $C C$ are represented as fixed to W, but such is not really the case, as will be seen in Fig. 147. The number of turns and size of conductor on the coils of course depend upon the range of the instrument. The terminal leads for connection to the outside circuit may be seen to the left of Fig. 147, marked $T T$.

* 144. Siemens' Electro-dynamometer. This instrument, which may be used to measure either direct or alternating currents, depends for its action upon the mutual attraction or repulsion which takes place between adjacent parts of a circuit (§ 69). It (Fig. 150) is constructed with three coils of wire, two of which (each consisting of several turns) are fixed, while the other, which encloses the fixed coils, and has only three or four turns, is movable.

Fig. 149 illustrates the action of the instrument diagrammatically. The movable coil $A B C D$ is suspended by a thread and helical spring $S S$ from a thumb-screw $T S$, and its ends dip in mercury cups $M C$: $E F G H$ is one of the fixed coils; both coils being represented by one turn only. Only one of the fixed coils, and two terminals are represented, for simplicity's sake. The coils are connected up in series, and when at rest, the movable coil is at right angles to the fixed coil.

The two fixed coils (Fig. 150) are of a different number of turns, of thick and thin wire respectively, and admit of two ranges of measurements being made with one instrument; small currents being measured on the thin wire coil, and larger currents on the thick wire coil.

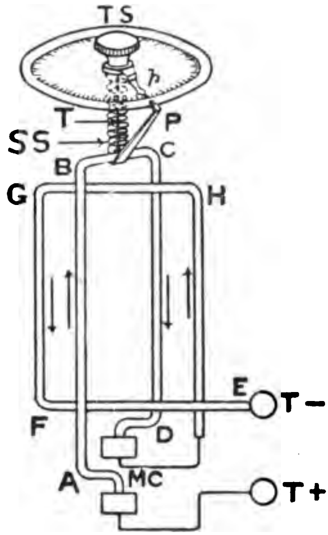


Fig. 149. Diagram of Electro-Dynamometer.

The swinging coil can be connected in series with either of the fixed coils, according to the terminals used. The centre terminal is connected with the lower mercury cup, the left-hand terminal to the thick wire coil, and the right-hand terminal to the thin wire coil. The other ends of both fixed coils are connected with

the upper mercury cup. One conductor from the circuit is always joined up with the centre terminal, and the other with either the right or left-hand terminal, according as the thin or thick fixed coil is required. The student should make a sketch, after the style of Fig. 149, to illustrate these connections.

Fig. 150. Siemens' Electro-Dynamometer

When the current to be measured passes through both coils, the movable one tends to turn against the tension of the helical spring, so as to place its plane parallel with the plane of the fixed coil. When the coil is deflected by the passage of a current, the thumb-screw *T S* at the top of the instrument, which is connected with the helical spring *S S*, is turned

in the opposite direction until the tension of the spring brings the pointer P, which is fixed to the movable coil, back to zero. The amount of this turning is indicated by the pointer p fixed to the milled head. When the coil is brought back to zero, *the current is proportional to the square root of the angle through which the spring has been twisted.* The force of torsion of the spring is proportional to the angle of torsion, *i.e.* to the amount it has been turned. The force of the current in turning the coil is proportional to the square of the current. Consequently the current is proportional to the square root of the angle of torsion of the spring as indicated on the dial.

* 145. WATTMETERS. From what was said in § 33, it must be clear that the power absorbed in any given part of a circuit may be ascertained by connecting a voltmeter to the points between which is the part of the circuit under consideration, at the same time inserting an ammeter in the circuit. Then the product of volts × amperes = watts.

Wattmeters are instruments which may be described as combined am- and voltmeters, and which more or less directly indicate the power used up in a circuit. As in the ohmmeter and dynamometer, there are two coils or sets of coils, one of which is fixed and the other movable. Lord Kelvin's wattmeters are somewhat similar in construction to his current balances (§ 143).

* 146. SIEMENS' WATTMETER. The principle of this instrument is indicated by the diagram Fig. 151

C is a coil of thick wire, which is free to turn against the torsion of a helical spring $S\,S$, on which it is suspended, as well as by a thread, as in the dynamometer: C is connected, through mercury cups $M\,C$, with the terminals T_1 and T_2. Inside C is a fixed coil V of fine wire, the ends of which are in connection with the

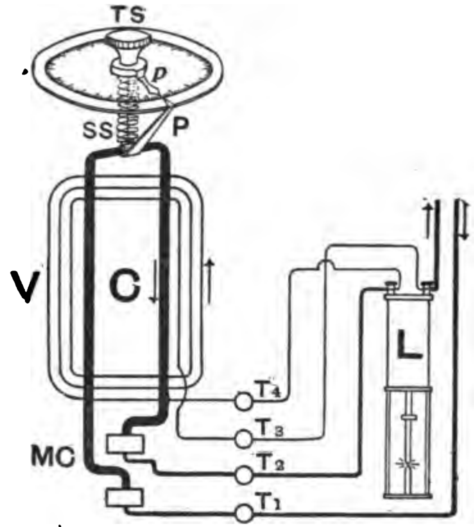


Fig. 151. Diagram of Siemen's Wattmeter.

terminals T_3 and T_4. The coil C has a pointer P fixed to it, which indicates the amount of its movement upon the scale.

The normal position of the coil C is as shown in the figure, *i.e.*, its axis is at right angles with the axis of the fixed coil V. It is evident that if both

coils carry current, the coil C will tend to turn so that its internal field shall lie parallel with the internal field of the coil V. To use the instrument, T_1 and T_2 are joined up in the main circuit, so that the whole current passes through the coil C as if it formed an ammeter coil, this being the reason it is wound with thick wire. The terminals T_3 and T_4 are joined up with the two points of the circuit between which it is desired to measure the power or rate of working; for instance to the terminals of a lamp L. The coil V thus acts as a voltmeter coil, and this is the reason for winding it with fine wire (§ 125). The coil V carries a current which is proportional to the volts at its terminals, while the coil C carries the main current. The force of turning exerted by the coils is proportional to the products of the strengths of currents in them; but as we said just now, the current in V is proportional to the volts: consequently the amount of turning of V is proportional to the product volts × amperes, *i.e.* watts. Siemens' wattmeter is very similar in appearance to the electro-dynamometer (Fig. 150).

147. SWINBURNE'S NON-INDUCTIVE WATTMETER. The special object of this instrument is to measure power in alternate current circuits. The main current passes through two fixed coils of copper strip, while the pressure is applied through a high non-inductive resistance to a small suspended coil having about 70 or 80 turns of very fine wire. This non-inductive resistance must be employed, otherwise the constantly alternating current would, owing to the self-induction,

considerably alter the true value of the indications of the instrument. The fields produced by the large and small coils being at right angles, and the small coil being between the two large ones and in the centre; it can be shown that the torsion needed to keep the small coil in its normal position, by twisting the top of the suspending wire is proportional to the mean

Fig. 152. Swinburne's Wattmeter.

product of the two currents; and as, on account of the negligible self-induction of the fine wire coil, and the large amount of non-inductive resistance in series with it, the current which passes through it is proportional and practically in step with the pressure on it; the torsion is proportional to the watts used between the two points tested. The current taken by the small coil is from $\frac{1}{80}$ to $\frac{1}{100}$ of an ampere, and for over 100

volts, separate outside resistances have to be used. In Fig. 153 one of the fixed coils is removed to allow the small movable coil to be seen.

The difference between the Siemens and Swinburne wattmeters is that the coils are different in shape and

Fig. 153. Swinburne's Wattmeter (cover and one coil removed)

differently disposed. In the Swinburne instrument, the fixed coils carry the main current, and the moving coil the pressure current.

The diagram (Fig. 154) shows how the instrument should be connected for use on say 2,000 volt mains. *D* is the dynamo, *W* the wattmeter, and R_1 R_2 two

non-inductive resistances of about 100,000 ohms each. *P* represents the circuit whose power is to be measured. The main current from the dynamo runs through the fixed coils of the wattmeter before going to the circuit *P*. The resistances, which are apart from the wattmeter in this case, in order not to have any great difference of potential within the instrument itself, are joined up in series with the suspended coil, and connected voltmeter fashion with the two points of the circuit under test.

Fig. 152 shows the exterior of the instrument. The

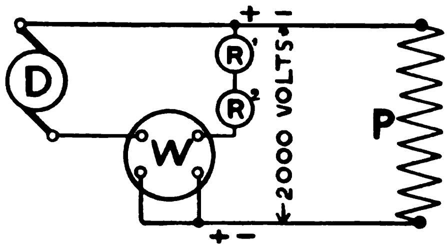


Fig. 154. Connection of Swinburne's Wattmeter to Circuit.

milled head, pointer, and scale serve to bring the suspended coil to its normal position, and to measure the angle of torsion indicating the watts. The window in front illuminates another pointer fixed to the suspended coil, so that by looking down from the top of the instrument through a hole directly above the window, the operator can see when this pointer (and therefore the coil) is at zero. The four terminals in front can be used for three different pressures from say

20 to 100 volts without external resistances; above that pressure the resistances become too large to insert in the base, and they have then to be put in separate cases, as in Fig. 154.

Fig. 153 shows the interior with one of the fixed coils removed. These coils slide on four horizontal parallel rods, and are screwed together by nuts, so that several pairs of coil can be supplied with each instrument, giving a great current as well as a great pressure range; and at the same time great sensitiveness. The suspending wire is of 3 mil phosphor bronze, and a similar wire is taken from the bottom to a spring, which keeps both wires taut, and this makes the instrument less affected by bad levelling than when mercury cups are employed. A screw in the base serves to take the tension off, and at the same time to clamp the suspended coil between two stops, so that the instrument is perfectly portable.

Swinburne's "U"-type wattmeter is on the principle of the instruments described in § 134, and has already been briefly alluded to.

148. RECORDING AM- AND VOLTMETERS. In certain cases it is necessary or useful to have a permanent record of the current or pressure in a circuit during an extended period, say 24 hours; such record showing every variation, and the time of its occurrence. Instruments for this purpose are called *recording ammeters or voltmeters*, and an example of each kind, working on the hot-wire principle, and therefore available for both direct or alternating currents, is shown in Figs. 155

and 156. These instruments were devised by Major Holden, R.A., and are made by Mr. Pitkin.

The current (which is proportional to the amperes or volts as the case may be,) passes through stretched

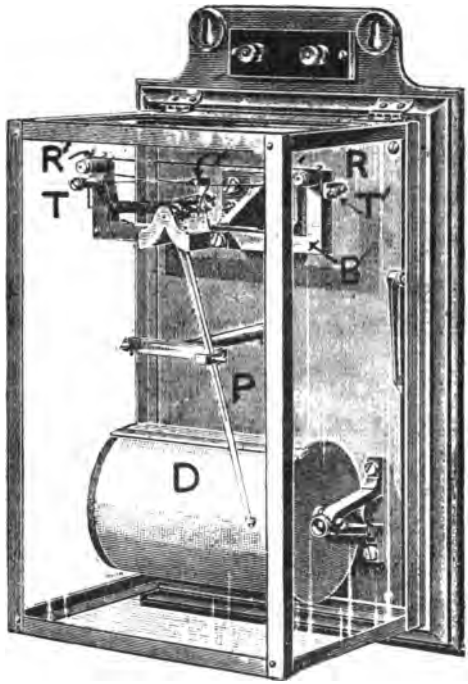


Fig. 155. Recording Voltmeter.

wires at the top of the apparatus, and heats them to a greater or less extent, the sag thus brought about allowing motion of an arm or pointer which ter-

minates in a pencil. A chart, divided by horizontal and vertical lines into voltage (or current) and time divisions, is mounted on a drum *D*, containing clock-

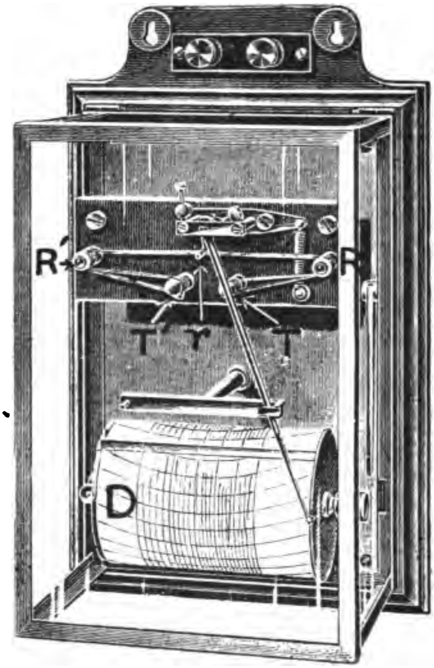


Fig. 156. Recording Ammeter.

work, which rotates it once every 24 hours. The pencil at the end of the arm bears against the paper, and thus a continuous line is drawn across the chart.

In the recording voltmeter (Fig. 155), *B* is a brass

bracket, on which are two pivoted insulating rollers *R* and *R′*. Fine wire of special alloy, made for strength and durability, is wound several times round *R* and *R′*, its ends being connected with the terminals *T* and *T′*. A smaller roller *r* of insulating material rests on the lower turns of wire, and when the latter sag owing to the heat developed by the current, *r*, which is linked to a small lever on the axle of the pointer or pencil, allows the latter to move by its own weight across the recording sheet. The current, the sag, and the deflection of the pencil are thus all three proportional to the pressure at the terminals. There is also an arrangement for compensating for changes of temperature other than those brought about by the current.

The recording ammeter is very much the same in principle, except that the current, instead of going round the various turns of wire in series, as in the voltmeter, divides between them in parallel. The wire is wound around *T·T′* the terminals, and *R R′* the rollers, as shown in the figure.

149. Summary. The measurements principally dealt with in this chapter are those of resistance, pressure, current, and power.

E.M.F. or P.D. (or pressure) is measured indirectly by a potentiometer, and directly by a voltmeter. Thus a direct-reading instrument is one which, when joined in circuit, at once indicates the required value. Pressure and its variation may be recorded on a recording voltmeter.

Current is indirectly measurable by various forms

of galvanometers, provided they have been previously calibrated, and a calibration curve obtained. The current balance and electro-dynamometer are also indirect measurers of current. Ammeters measure currents directly. Current and its variation may be recorded on a recording ammeter.

Most of the methods of measuring resistance (substitution, differential galvanometer, Wheatstone and slide-wire bridges,) are indirect; but the ohmmeter is a direct-reading instrument, although indirect in principle.

An indirect but handy method of measuring the power in a continuous current circuit or part of a circuit, is by means of the combined use of an ammeter and voltmeter. Wattmeters are direct measurers of power.

All voltmeters may be classified under three heads, according as they are *electrostatic*, *hot wire*, or *electro-magnetic*. Most ammeters belong to the latter class, though there are a few which come under the second heading. There are, of course, no electrostatic ammeters. The controlling force of the majority of instruments is gravity, but many depend upon the torsion of a spring or flat strip to bring the movable part back to zero.

CHAPTER VII.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. What are the principal measurements necessary in electrical work?

2. Give an ideal sketch and explanation of the instrument

and method for the determination of the Board of Trade standard of current.

3. Define the Board of Trade standards of pressure and resistance.

*4. What are standard resistance coils, and how are they constructed?

*5. How would you wind a coil so that it should have no inductance? Give reasons.

*6. Show by a sketch how resistance coils are generally mounted.

*7. Give reasons for using a shunt to the galvanometer in Fig. 86.

*8. Which is the quicker method of measuring resistance, by substitution or with a differential galvanometer: and why?

9. A constant non-polarising battery is necessary for the substitution method, but is not essential for the differential galv. method of measuring resistance. Thus a Leclanché battery will suffice for the latter test, but not for the former. Give reasons for these statements.

*10. Give a diagram of the Post Office form of Wheatstone bridge, showing the connections. [Prel. 1895.]

11. Describe in your own words the theory of the Wheatstone bridge.

12. In Wheatstone or metre bridge measurements, why is it necessary to close the battery circuit before closing the galv. circuit; and to open the latter before the former?

13. What are the essentials in a galv. to be used in the measurement of resistance by substitution, or by the Wheatstone bridge?

14. Sketch the connections of a Wheatstone bridge, showing how it is connected to the resistance to be measured. [Ord. 1894.]

15. Describe the construction, and two methods of use of the metre bridge.

16. In what respects does the slide-wire bridge differ from the Wheatstone bridge?

17. What values of resistance are the metre bridge, Wheatstone bridge, and ohmmeter respectively adapted for measuring?

18. In a Wheatstone bridge measurement, if the resistances in the arms b, a, and R (Fig. 92), are respectively 1000ω, 100ω, and 565ω when balance is obtained, what is the value of the unknown resistance x?

19. In a slide-wire bridge measurement, if (Fig. 93) the known resistances a', b, and R' are 5, 10, and 5ω, and the lengths of the divisions a and R of the slide wire respectively 57 and 43, what is the value of x?

20. What is the construction of an ohmmeter? [Ord. 1895.]

21. Draw a diagram of, and explain concisely the principle of the ohmmeter.

22. Explain how you would measure the insulation resistance between the + and − leads of a circuit by means of an ohmmeter.

23. In how many ways could you measure the resistance of a wire?

24. You are required to fit up on a bench certain apparatus whereby E.M.F., P.D., and current may be measured by the potentiometer method. Describe the apparatus required, and give a sketch of the arrangement of the same, indicating clearly the difference in the connections for the different tests.

*25. Sketch and describe the construction of the ordinary and astatic detector galvanometers.

*26. Sketch some form of reflecting galvanometer with moving needle, and say why reflecting galvanometers are so much more sensitive than non-reflecting ones.

*27. Sketch your idea of a lamp-stand, lens, and scale for use with a mirror galvanometer.

*28. Describe the Holden-D'Arsonval galvanometer for use with direct currents, giving one sketch only.

29. Explain the principle of the tangent galvanometer.

30. Describe any form of portable testing apparatus with which you are acquainted, and say what tests may be performed with it.

*31. How would you test the insulation in a building you had wired? [Prel. 1895.]

*32. What is the difference between an ammeter and a voltmeter?

*33. In using ammeters and voltmeters, how should they be joined up with the circuit?

*34. What influence has a change of temperature upon the resistance of a wire?

*35. What are hot-wire instruments?

*36. Sketch and describe the action of the working parts of the Cardew voltmeter.

*37. State the principles on which the Cardew voltmeter is based. [Prel. 1894.]

38. Can ammeters be constructed on the hot-wire principle? Give reasons for your answer.

*39. Sketch and describe the working parts and action of the Holden, Drake, and Gorham cell-tester.

40. Describe the principle of Ayrton and Perry's twisted strip instruments.

41. Describe the action of Lord Kelvin's vertical and horizontal electrostatic voltmeters; and say why these and similar instruments are so well adapted for the measurement of high differences of potential.

42. Describe and give a full-size hand sketch of one of the modern kinds of electrostatic voltmeters. [Ord. 1895.]

43. Explain clearly the difference in construction between the Swinburne, and Ayrton and Mather electrostatic voltmeters.

*44. Sketch and describe the principle of Evershed's gravity instruments.

*45. Give a sectional sketch and a description of Ayrton and Perry's spring ammeter.

46. Why is it that, as a general rule, ammeters and voltmeters constructed for use in direct-current work are not adapted for alternating current work?

47. Name any voltmeters you know of that will do for both direct and alternating-current work without any modification, and say why such is the case.

*48. What is generally the difference between voltmeters and amperemeters of the same type? [Prel. 1895.]

*49. Describe Paterson and Cooper's "Phœnix" ammeter.

50. Make a list of those ammeters or voltmeters in which the force of gravity is pitted against the action of the current, and give simple sketches of the moving parts of each kind.

51. Sketch some form of gravity ammeter or voltmeter. [Ord. 1890.]

*52. Describe the Holden, Drake, and Gorham ammeter.

*53. Sketch and describe the mode of action of the Schuckert instruments.

54. In such an instrument as the above, if the armature is very short relatively to the length of the coil, it depends upon the position of the armature whether it will be attracted to the centre (axis) or side of the coil. Why is this?

55. Sketch the details of any good form of instrument for measuring the strength of an electric current. [Ord. 1891.]

56. Describe and sketch some form of amperemeter of a type which does not depend on the magnetization of iron. [Ord. 1894.]

*57. Describe the working parts of the Walsall instruments.

58. Describe and illustrate by hand sketches the construction of Lord Kelvin's (Sir William Thomson's) ampere balance. [Ord. 1893.]

59. Give a diagrammatic sketch and explain the action of the electro-dynamometer.

60. Explain the construction and action of Siemens' electro-dynamometer, and show why the current is proportional to the square root of the scale reading. [Ord. 1892.]

61. Explain how you would measure a current by the electro-dynamometer.

*62. Explain clearly the difference between ammeters, electro-dynamometers, and wattmeters.

63. Redraw and add to Fig. 149, showing two fixed coils and three terminals, as in the actual apparatus (Fig. 150). Represent each coil by one turn only, and explain the use of the different terminals.

64. Describe a wattmeter. [Ord. 1891.]

65. Show how Siemens' and Swinburne's wattmeters differ from each other.

66. How can a continuous record of the current or pressure in a circuit be kept?

67. Describe some form of ammeter or voltmeter that is not mentioned in this chapter.

68. Draw up a list of all the current and pressure measurers described in this chapter, and classify them under the following heads:—*hot-wire*, *electrostatic*, *electromagnetic*, *controlling force*, and say of each type whether it requires modification for alternating current work.

69. Give a sketch, roughly to scale, showing parts full size, of a d'Arsonval

galvanometer, and describe particularly how the current flows through it. [Ord. 1896.]

70. Briefly describe the Clark standard cell. [Ord. 1896.]

*71. What is the difference as regards construction and use, between an ammeter and a voltmeter? [Prel. 1897.]

72. The key for a Wheatstone's bridge makes two contacts in succession. What are the circuits that are closed by each of these contacts, and is there any reason for closing one before the other? [Ord. 1897.]

73. What forms of ammeters and voltmeters are likely to be affected by neighbouring current circuits—for instance, those on a switch-board—and what are the forms that are practically unaffected? [Ord. 1897.]

74. What are the special advantages and disadvantages of electrostatic voltmeters as compared with current voltmeters? Describe in detail some form of electrostatic voltmeter that is suitable for use in a central station. [Ord. 1897.]

*75. Give a diagram of the connections of a resistance set, such as is used in the testing of the insulation of house-wiring. [Prel. 1898.]

*76. Describe the construction and use of a wattmeter. Give sketches. [Prel. 1898.]

77. Give the particulars of a resistance frame of two ohms to carry 10 amperes, with sketches of the principal dimensions. [Ord. 1898.]

78. Describe, with sketches, some form of moving-coil voltmeter. What are the advantages of this type? [Ord. 1898.]

79. Describe a good form of voltmeter for use on an alternating current system. [Ord. 1898.]

*80. Describe, with sketches, some form of accurate portable testing set used for measuring the insulation resistance of an electric light installation. [Prel. 1899 and 1900.]

*81. How does a voltmeter differ from an ammeter in its construction and use? What sort of resistance may be given to a voltmeter used with a single accumulator? [Prel. 1899.]

82. Describe, with rough dimensional sketches, a good form of standard resistance having a value of 0·001 ohm, and explain how it is used in the measurement of large currents. [Ord. 1899.]

83. Describe the construction and use of a wattmeter, and state what are the important points to be attended to if the wattmeter is to be used on an alternate current circuit. [Ord. 1900.]

84. Give a *detailed* account of the *complete* method of constructing a permanent magnet to be used in a moving coil ammeter. [Ord. 1900.]

85. A specimen of insulated conductor, about 100 ft. long, is submitted to you to test. It is said to have an insulation resistance of 2,000 megohms per mile after soaking in water for twenty-four hours, and when tested at 600 volts at a temperature of 60° F. Describe exactly how you would ascertain whether this was true, and mention all the precautions you would adopt to avoid errors. [Ord. 1900.]

*86. What is a wattmeter, and what does it measure? Give sketches showing some form of wattmeter suitable for use in a workshop. [Prel. 1901.]

CHAPTER VIII.

The figures refer to the numbered paragraphs.

* 150. PRINCIPLE OF THE DYNAMO. It was explained in § 60 that when a conductor is moved in any magnetic field, across the lines of force, an E.M.F. is set up in the conductor, which will give rise to a current if the conductor forms part of a closed circuit. This is the principle of most *dynamos*, which may be generally defined as machines for developing electromotive force, or difference of electrical potential, by the movement of coils of wire in magnetic fields.

* 151. The different kinds of Dynamo. Dynamos are divided into two principal classes, *continuous current dynamos*, and *alternating current dynamos* or *alternators.* Continuous, or, as they are sometimes called, *direct current dynamos*, consist essentially of three parts :—

(*a*) The *field magnet or magnets* which furnish the magnetic field in which the armature rotates.

(*b*) The *armature*, consisting of coils of wire which are rotated in the magnetic field of the field magnets, and thus have electromotive force induced in them ; and

(*c*) The *commutator*, an arrangement whereby the electromotive forces which are developed in alternate directions in the armature coils, are rendered unidirectional, and thus give rise to direct currents in the external circuit.

Alternators have also field magnets and an armature, but in place of a commutator, devices called *collectors* are employed, which consist simply of insulated rings upon the armature shaft. A commutator is not necessary in an alternator, as it is intended that the alternating electromotive forces induced in the armature coils shall be delivered as such to the external circuit, and so give rise to an alternating current. In more technical language, the alternating electromotive forces are *impressed* on the external circuit. It will thus be seen that all direct current machines are really alternators whose currents are *rectified* or rendered unidirectional (*i.e.*, sent in one direction,) by means of a commutator.

* 152. ELECTRO-MAGNETIC INDUCTION. Let us first of all consider a simple case of electro-magnetic induction. In Fig. 157, *N S* are the poles of two bar magnets set close together, but not touching: *a b* is a wire forming part of a closed circuit which includes a galvanometer *G*. If *a b* is moved downwards across the magnetic field between the poles *N* and *S*, an E.M.F. will be induced, which will give rise to a current in the direction from *a* to *b*. If *a b* is below the field, and is then moved upwards, a current will be set up in the opposite direction, *viz.* from *b* to *a*. The student should verify

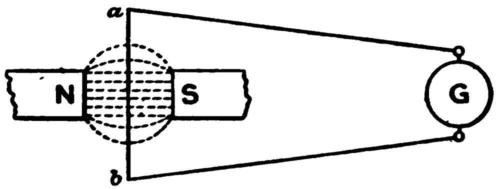


Fig. 157. Electro-magnetic Induction.

for himself these and following statements as to the direction of induced currents, by applying the left-hand rule (§ 63).

* 153. SIMPLE ALTERNATOR. In Fig. 158, *a b c d* is a simple coil of wire of one turn, fixed to the spindle *S*, by means of which it may be rotated in the magnetic field *N S*. The ends of the coil are fastened each to an insulated metal ring *r* on the spindle, and against these collecting rings press the metal springs or *brushes B B′*, which lead the currents round the external circuit. Let us suppose first of all that the coil is in the position

shown in the figure, and that it is given a half turn in the direction shown by the arrow. One-half *a b* of the coil will descend across the field, while the other half *c d* will ascend. The induced electromotive forces will give rise to currents from back to front in *a b*, and from front to back in *c d*. The currents, or rather the electromotive forces in the two halves of the coil will thus act together, and a current will flow round the

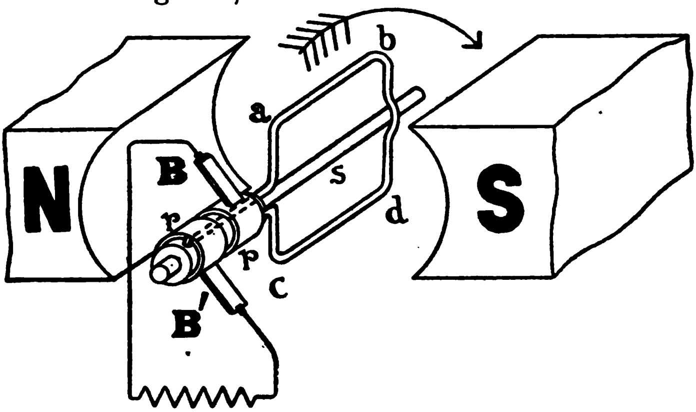


Fig. 158. Simple Alternator.

external circuit from the brush *B* to the brush *B'*. When the coil has made one half-turn, that is, when *a b* is at the bottom and *c d* at the top, *a b* will begin to ascend across the field to its first position, while *c d* will descend; the induced electromotive forces will thus be in a direction from front to back in *a b*, and from back to front in *c d*; that is, in the opposite direction to the first E.M.Fs.; a current will consequently

flow round the external circuit in the opposite direction, *viz.* from B' to B. Thus it will be seen that for every complete revolution of the coil, two currents, in opposite directions, will be sent round the external circuit: and if the coil be continuously rotated, an alternating current will be set up. The ends of the coil *a c* and *b d* will have no E.M.F. induced in them, as they are merely slipping between the lines of force, and consequently do not cut them.

Alternating currents and alternators will be dealt with in Chapters XI. and XII. respectively.

* 154. SIMPLE DIRECT-CURRENT DYNAMO. Fig. 159 represents a simple coil of wire *a b c d* capable of rotation on the shaft *s s* in the magnetic field between *N* and *S*. The ends of the coil, instead of being joined to collecting rings as in the case of the simple alternator described in the preceding paragraph, are connected each with one-half of a split metal tube mounted on, but insulated from the spindle and each other by means of the boss *e*, which is made of hardwood, ebonite, or other insulating material. This arrangement is called a *two-part commutator*, and the brushes are arranged so as to press on exactly opposite points of it; this ensures that they shall never be pressing on the same *segment* or part of the commutator at the same time.

Starting with the coil in the position shown in the figure, and rotating it in the direction indicated by the large curved arrow, electromotive force will be induced in a direction from back to front in *a b*, and from front

to back in *cd*. This will continue while the coil is making one half turn, and as during that time the end *a* of the coil is connected through segment *S* of the commutator with the brush *B* +, while the other end of the coil is connected with brush *B* – through the segment *S′*, a current will flow round the external circuit in the direction shown by the arrow.

As was explained in the preceding paragraph, as

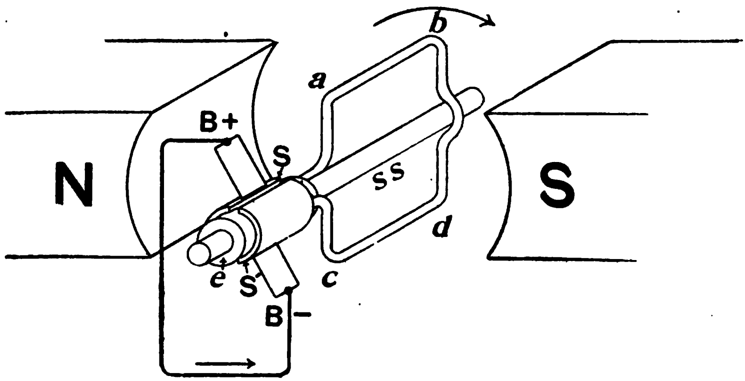


Fig. 159. Simple Direct-Current Dynamo.

soon as the coil begins its second half revolution, electromotive force is induced in the opposite direction; but in the present case it will be seen that as soon as the direction of the E.M.F. changes, the connection of the coil with the external circuit is reversed by means of the commutator, the brush *B* + being then in contact with *S′*, and the brush *B* – with *S*. The resulting current therefore flows round the external

circuit in the same direction as before. As soon as the coil regains its first position, the commutator once more reverses its connection with the outer circuit.

In this and in most other armatures, the brushes are fixed almost end on to the commutator. In order therefore to prevent the brushes from catching, the spaces between the conducting segments are filled up with mica or other suitable non-conductor. This is not shown in Fig. 159, but will be understood from Fig. 184.

In Figs. 158 and 159, a coil of but one turn is shown for the sake of simplicity, but an increased E.M.F. will be obtained by having a coil of several turns, and joining its two ends to the collecting rings or to the commutator, for this increases the length of the conductor acted upon by the lines of force. In fact, the E.M.F. (E) induced in the coil or armature may be increased in either of three ways:—

(i.) By increasing the number of turns, *i.e.* the length (L).
(ii.) By revolving the coil at a greater rate (V).
(iii.) By strengthening the magnetic field (H).

This latter may be accomplished either by increasing the strength of the field-magnet *N S*, or by winding the armature on an iron core. The effect of introducing this iron core is to reduce the reluctance of the space between the field-magnet poles, and thereby to increase the flux through the armature for a given magnetic force in the field magnets.

The simple equation which expresses these facts may be written:—

$$E \propto L \times H \times V$$

indicating that the E.M.F. is directly proportional to the length of conductor on the armature, to the strength of the field, and to the velocity with which the conductor cuts the lines of force of the field.

* 155. HAND DYNAMO. The student must clearly

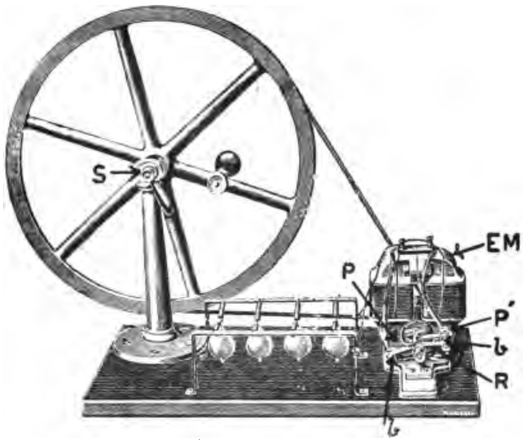


Fig. 160. Hand Dynamo.

understand that Figs. 158 and 159 represent the action of dynamos diagrammatically, and that practical machines are necessarily complex in design. Fig. 160 illustrates a dynamo[1] on the same principle as that just described, but having a coil of many turns wound

[1] Made by the Crypto Works Co., Clerkenwell, London.

on an iron core shaped like a shuttle. This kind of armature, known as the *Siemens' H* or *shuttle armature*, is a great favourite with amateurs because of its ease of construction, but it is very little employed in practical machines. A description of the dynamo will, however, be of interest to the student.

E M is an electro-magnet made in two halves for convenience in winding, and bolted together at the yoke. The magnet is provided with *pole pieces P P'*, which are so shaped as to almost enclose the armature. For certain reasons, which will hereafter be fully explained (§ 164), the iron core of the armature is not solid, but is built up of thin iron stampings which are threaded side by side on to the spindle of the machine, and tightly clamped together. The coil is connected with a two-part commutator. Fig. 161 shows the armature core unwound, and also the two-part commutator. The brushes are held in the *brush-holders b b*, the latter being supported on, but insulated from the *rocker R*, which allows of their being adjusted at any angle. *R* is tightened in position by means of the set screw seen in the figure.

The machine, like most others that will be presently described, is a true dynamo, in that it is *self-exciting*, *i.e.*, it furnishes the current for its own F.M. When a dynamo is first run, it is necessary to separately excite the F.Ms. by current from a battery or from another dynamo. After having once been excited, the F.Ms. retain a certain amount of residual magnetism. This residual magnetism provides a very

weak field, and the armature in revolving consequently generates only a comparatively weak current, but as this current is led round the F.Ms. (§ 169) it strengthens them, and so provides a stronger field, and the armature therefore generates a stronger current. And so the process goes on until the F.Ms. get excited to their full strength. In large machines, this operation may take a minute or even more.

The machine being shunt-wound (§ 169). the ends of

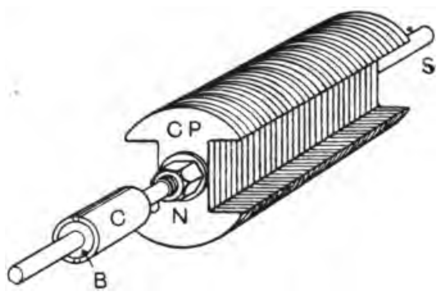


Fig. 161. Iron Core of Shuttle Armature.

the F.M. coils, as well as the brushes, are connected with the terminals at the top. From these, wires are led to two bent brass pieces between which are slung four incandescent lamps. The driving wheel axle is so arranged that when the belt gets loose, it may be tightened by moving the axle to the left in the slot *S* in the stand. This model is very convenient for illustrating incandescent lighting, the usual size being fitted with ten-volt lamps; but of course the current may be used for other purposes.

* 156. Different kinds of Armature. Direct-current dynamo armatures are of four principal kinds:—(*a*) *ring*; (*b*) *cylinder*; (*c*) *drum*; and (*d*) *disk*. Ring armatures are those in which the coils are wound around and through a ring built up of soft annealed iron plates or wire. A cylinder armature is an elongated ring armature. A drum armature is one in which the coils are wound from end to end upon the face of a cylinder or drum, which is built up of disks

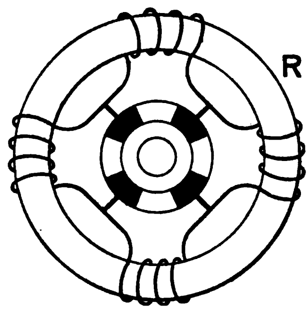


Fig. 162. Four-part Ring Armature.

of soft iron threaded upon the armature shaft. Disk armatures are of two kinds, according as they are for use in alternators or direct-current machines. In the latter case the coils are wound radially around a disk of soft iron wire or ribbon; forming in fact, a kind of flattened ring armature. (§ 161.)

Alternator armatures will be considered in Chapter XII.

* 157. The Gramme or Ring Armature. The prin-

ciple of the Gramme or ring armature (so called from the name of the first maker,) is illustrated in Fig. 162. *R* is a ring which is built up by clamping together a number of annealed soft iron pieces shaped like very large washers. This part is called the *armature core.* The method of fixing the core to the shaft or axle is omitted for the sake of simplicity. For the same reason only four coils are shown, whereas in reality the whole of the core would be covered with

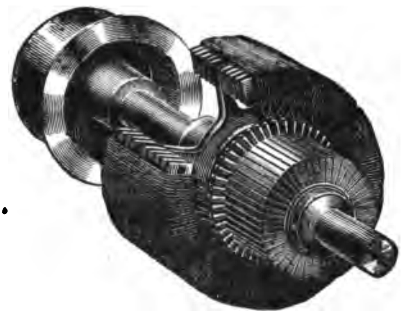


Fig. 163.

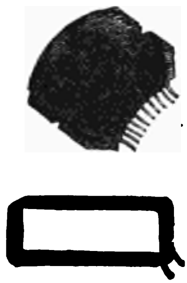


Fig. 164.

Parts of Joel Ring Armature.

coils. The end of one coil is generally, as in this case, joined to the beginning of the next, and the junction between each pair of coils is connected with a separate commutator segment. The number of commutator segments thus depends upon, and is equal to the number of coils, on an armature of this kind.

Fig. 163 shows an actual ring armature with part of the core removed, so as to expose the armature *core-plates* and the gun-metal *spider* by which they are

fastened to the shaft. Fig. 164 shows a portion of the core wound with coils, and also a separate coil. The coils are separately wound, and threaded on to the core one after the other. The particular armature shown in the figure is or was used in the Joel dynamo, and its iron core was of special construction, enabling segments of it, together with the coils, to be removed for repair, etc.

As a rule the iron core-plates are in one piece, one

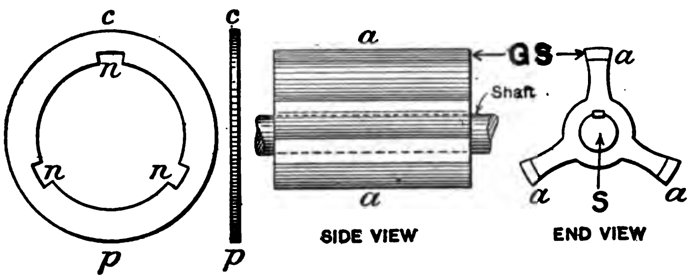


Fig. 165. Armature Core-Plate and Spider.

form being shown in Fig. 165, where *c p* is a core-plate with notches *n n n* cut on the inside edge. At the right hand of the figure is represented an end view of the shaft and "spider" on which the core-plates are mounted. *S* is the shaft, and *G S* the "spider," which is made of gun-metal or other non-magnetic metal. This spider has three radial arms, *a a a*, the extremities of which are shaped to fit the notches in the core-plates. In the drawing, the ends of these arms as well

as the slots in the core-plates are somewhat exaggerated in size.

* 158. THE CYLINDER ARMATURE. The cylinder armature is merely an elongated ring armature, its length along the shaft being great compared with its diameter.

It will be seen later on that it is only the outer portions of the coils on a ring or cylinder armature that cut lines of force, the inner portions doing no work in this way, while the extra resistance diminishes the current that can be safely taken from the armature without the latter overheating. These inner turns of the wire on an armature, as well as those parts at the end which slip between, but do not cut lines of force, are often called *idle wire.*

* 159. THE DRUM ARMATURE. Fig. 166 illustrates the coil connections of an ordinary drum armature. *S* is the shaft, the front end being cut away to show the commutator segments more clearly. *C* is the core, made up of thin soft iron plates, which are often fixed directly to the shaft without the use of a spider.

Fig. 167 shows a core-plate with an hexagonal hole stamped in it; the part of the shaft *S* on which the plates are mounted is shaped so as to fit the core-plates; magnetic contact between the two being prevented by the interposition of "leaves" or strips *L* of non-magnetic metal. There is thus no possibility of the core-plates slipping round upon the shaft, the consequences of which taking place would be very disastrous to the coils. There are various other

methods besides this of fixing the core-plates to the shaft: sometimes they are keyed on, and sometimes they are held by a short-armed spider.

Although, of course, the face of the armature does not touch the pole pieces as it revolves, there is a very considerable strain on it, caused by the reaction between the current in the armature coils and the

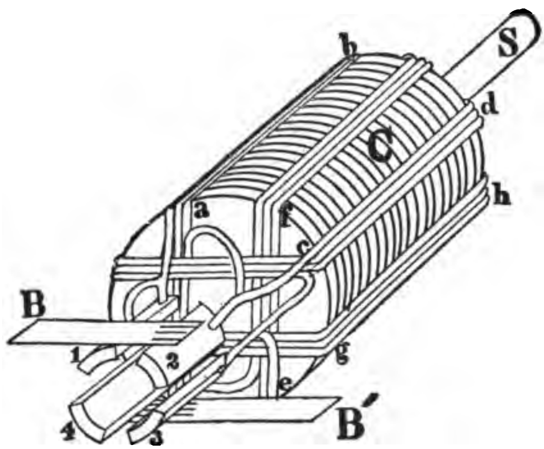


Fig. 166. Drum Armature.

magnetic field, the latter exerting a *magnetic drag* on the coils tending to stop their rotation, in accordance with Lenz's law (§ 65). If the coils and core-plates were not fixed firmly, this "drag" would cause both to slip round upon the shaft. By mounting the core-plates in the manner shown in Fig. 167, it is impossible for them to shift, and further, the face of the

core is sometimes slotted in a direction parallel with the shaft, and the coils wound in these slots. Thus both coils and core are driven direct from the shaft. In the figure, four of these slots are shown wound with wire. This method is extensively employed nowadays, and is further dealt with in § 181.

In Fig. 166 only four coils are shown for the sake of simplicity, but in an actual armature the whole surface of the core would be covered with coils, (except in cases where the core is slotted, as just described,) and

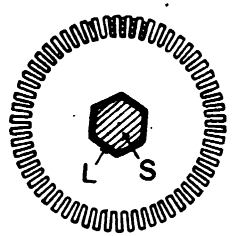


Fig. 167. Core-Plate of Drum Armature.

the number of commutator segments would correspond. Starting from segment 1, the coil *a b* makes so many turns (§ 162), and finishes at segment 2. From this starts the coil *c d*, finishing at segment 3. Between segments 3 and 4 is the coil *e f*; and between segments 4 and 1 the fourth and last coil *g h* is connected. Thus it will be seen, as in the case of ordinary ring and cylinder armatures, the end of one coil and the beginning of the next are connected with the same commutator segment. There is thus a complete circuit through all the coils. Such armatures are

sometimes called *closed-coil armatures*, to distinguish them from *open-coil armatures*, in which each coil, or at least one end of each, has separate commutator segments (§ 174).

* 160. DRIVING OF ARMATURE CONDUCTORS. The *driving of the armature conductors*, on account of the "drag" which the field exerts on them, is an important matter (Chaps. IX. and XIII.). One method, as already explained, is to cut slots in the core, and wind the conductor in the slots. Another method is to cut narrow slots in the core and insert strips or wedges of vulcanised fibre or even german silver, the conductor being wound between the ridges thus formed.

* 161. DISK ARMATURES. Disk armatures are of two kinds. (*a*) Those in which the coils are arranged on small bobbins fixed side by side round the circumference of a driving wheel; and (*b*) those in which the coils cover not only the edge, but a good portion of the sides of the wheel or disk which carries them. The armatures of some alternators belong to the first class (Chap. XII.); while of the second class there were a few examples in old direct current machines.

162. WINDING OF ARMATURES. The size of the wire on an armature, and the number of turns on any one armature coil depend upon the E.M.F. and output the machine is desired to have, and upon other circumstances which will be briefly considered in Chapter X. Except in one or two special cases, all the coils on an armature should have exactly the same number of turns.

163. Choice between Ring and Drum Armatures. In § 158 we explained what is meant by idle wire. The relative amounts of idle wire on a ring or a drum armature affect the choice of either type. With armatures of great length and small diameter, drum-winding gives the least amount of idle wire; but in armatures of large diameter as compared with length (Fig. 214), a ring-winding gives less idle wire, and

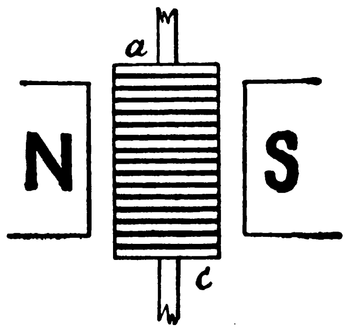


Fig. 168. Lamination of Armature Core.

is less trouble to build. Generally speaking, drum armatures are the most used.

* 164. Lamination of Armature Cores. Most armatures of direct current machines have iron cores, and the revolution of the cores in the magnetic field would, unless precautions were taken, cause currents to be induced in the core as well as in the armature coils, these induced currents completing their circuits and circulating in the core. Such currents, called *Foucault* or *eddy currents*, are detrimental in two ways.

Firstly, their generation absorbs energy and makes the dynamo all the harder to drive; and secondly, they may heat the core so much as to injure the insulation of the coils. To prevent this, the core must be built up of thin laminæ or sheets of soft iron, in such a way that the iron is continuous in the direction of the lines of force, but discontinuous in the direction in which the eddy currents would tend to be set up, *i.e.*, at right angles to the lines. This will be understood from a reference to Fig. 168, where *a c* is a shaft and armature core without any coils on, revolving in the magnetic field between the poles N. and S. of the dynamo. The primary object of the core is to afford the lines an easy path from the N. to the S. pole, and this object is attained, for the iron is continuous in that direction: while in a direction parallel with the shaft and at right angles with the lines of force of the field, *i.e.*, the direction in which the eddy currents tend to be induced, thin insulation, frequently in the form of sheets of paper, is interposed between each pair of plates, this being quite sufficient to retard, if not stop, the generation of these eddy currents in the core.

* 165. FIELD MAGNETS. Dynamos may be divided into four classes, according to the form of their field magnets.

(1) *Single-magnet* (or *single horseshoe*) } *Two-pole.*
(2) *Double-magnet* (or *double horseshoe*) }
(3) *Four-pole.*
(4) *Multipolar.* Having more than four poles.

Dynamos which belong to either of the first two

classes are called two-pole machines, to distinguish them from four-pole and multipolar machines. Nearly

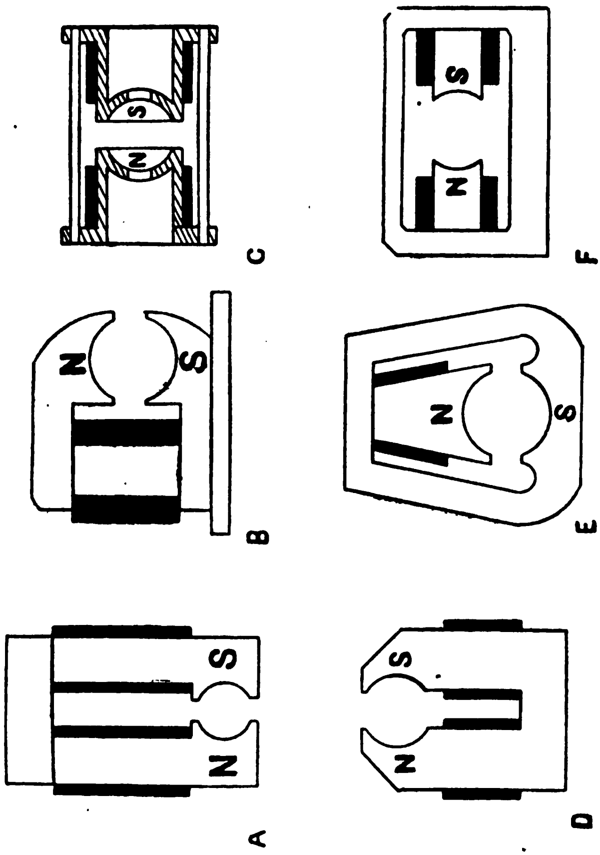


Fig. 169. Field Magnets of Single-Magnet Dynamos.

all alternators belong to the fourth class. (Chap. XII.)

Direct current dynamos may also be classified under different heads, according to the way in which their field magnets are excited (§ 169).

* 166. SINGLE-MAGNET MACHINES. A single-magnet dynamo is one in which the armature revolves between two *salient poles* N. and S., due to a horseshoe magnet. Fig. 169 shows six forms of magnet for single-magnet machines, the thick black parts representing sections across the wire coils. Fig. 169A is the form of magnet used in the Edison-Hopkinson machine (§ 188), and (with slight alterations) in a few other machines described in

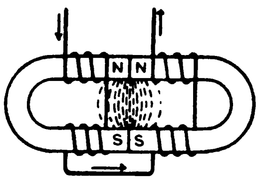


Fig. 170. Consequent Poles.

Chap. IX. *D* is possibly the most common shape of magnet in single magnet machines. Dynamos having field magnets of the shape *E*, in which, by the way, the lower pole is a consequent one, used to be constructed by a Midland firm. *F* is a section of the two-pole Lahmeyer machine, and type *C* is the form of F.M. used in the old Thomson-Houston arc dynamos, it being similar to *F* in principle.

* 167. DOUBLE-MAGNET MACHINES. A double-magnet machine is generally one in which two *consequent poles* are employed. *A salient pole* may be defined as

a single pole; thus the poles of all the magnets shown in Chap. III. are salient poles: a consequent pole is formed by the junction of two or more like poles. Thus, if two horseshoe electro-magnets be placed with

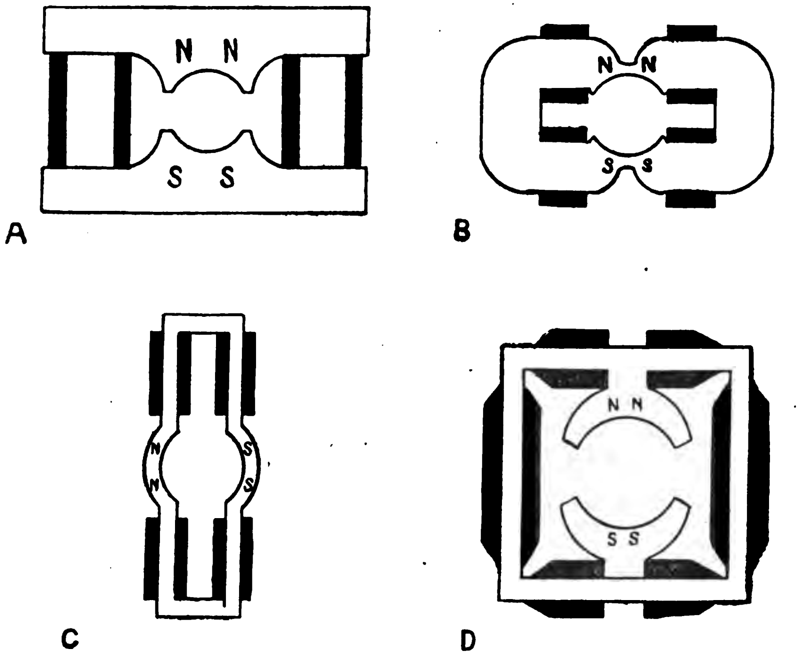


Fig. 171. **Field Magnets of Double-Magnet Dynamos.**

their like poles together, as shown in Fig. 170, we have a consequent N. and a consequent S. pole formed.

Fig. 171 shows four forms of F.Ms. of double-magnet machines. *A* is the type of magnet used in the Man-

chester and other dynamos. The *B* form differs from *A* in that there are two coils to each of the two magnets, instead of only one. The old type of "Norwich" dynamo, made by Messrs. Laurence, Scott & Co., had magnets of this shape. *C* is the same in principle as type *B*, except that the pole pieces are shaped differently, and the whole magnet stands up on end; this type was used in the old form of Siemens' direct-current machine. Type *D*, in which it will be noticed

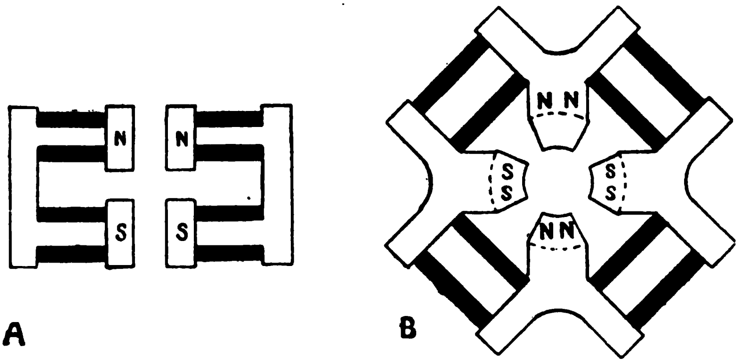


Fig. 172. Field Magnets of Four-Pole Dynamos.

that each magnet has three coils, was employed in the old Elwell-Parker machines, but is now quite obsolete.

In the early days of electric lighting many complicated forms of F.M. were used; but the tendency has since been to make these as simple as possible. Of the two-pole forms shown in Figs. 169 and 171, *A* and *D* (Fig. 169) and *A* (Fig. 171) are now the most used, as

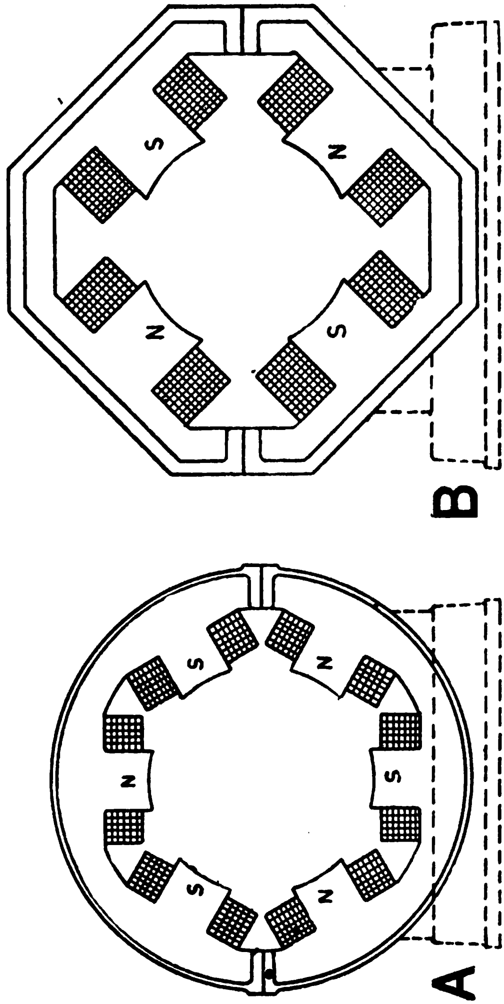


Fig. 173. Field Magnets of Four- and Six-Pole Dynamos.

will be seen on reference to the illustrations of actual machines in the next chapter.

* 168. MULTIPOLAR MACHINES. Multipolar machines are those in which the field is due to four or more poles. Two forms are shown in Fig. 172. The first example (*A*) has salient poles, and is employed in the Brush arc dynamo[1] (§ 196). The *B* type has consequent poles, this form being peculiar to a machine once made by Messrs. Ernest Scott & Mountain, but now quite obsolete. Fig. 173, *A* and *B*, shows sections of six and four-pole direct-current machines. Several examples of the latter will be found in Chap. IX.

* 169. EXCITATION OF DYNAMOS. We now come to the classification of dynamos according to the methods by which their field magnets are excited. It must be remembered, however, that the way in which a dynamo is excited is quite independent of the form of its field magnets. As most dynamos may be used as motors, the word *machine* is often used instead of the word *dynamo*.

(*a*) *Magneto machines* are those in which permanent magnets are employed as F.Ms. This class, as far as electric lighting is concerned, is now little used; although one form, the De Meritens, is still employed for lighthouse work.

(*b*) *Series machine* (Fig. 174A). In a series machine,

[1] This is not a true four-pole machine, as the poles are not alternate.

the current starting from the + brush goes first through the field magnets and then through the external circuit, or *vice versâ*. It follows, therefore, that the F.M. coils of a series machine must be wound with thick wire, otherwise the coils would overheat.

(*c*) *Shunt machine* (Fig. 174B). In a shunt machine, the F.M. coils form a shunt to the external circuit, the current from the armature dividing between the two. The coils of a shunt machine must be wound with comparatively fine wire, otherwise an unduly large proportion of the current will flow round the F.M. circuit, instead of through the external circuit.

(*d*) *Separately-excited machine* (Fig. 174C). In a separately excited machine, the current for the field magnets is furnished by a small auxiliary dynamo, which is called the *exciter*. Most alternators have to be separately excited; separate coil or partially rectified current alternators being exceptions (Chap. XII.).

A *compound machine* may be defined as one in which the method of exciting the field magnets is a combination of two simple methods.

There are three kinds, *viz.* (*e*) series and separately excited machine; (*f*) series and short-shunt; and (*g*) series and long-shunt.

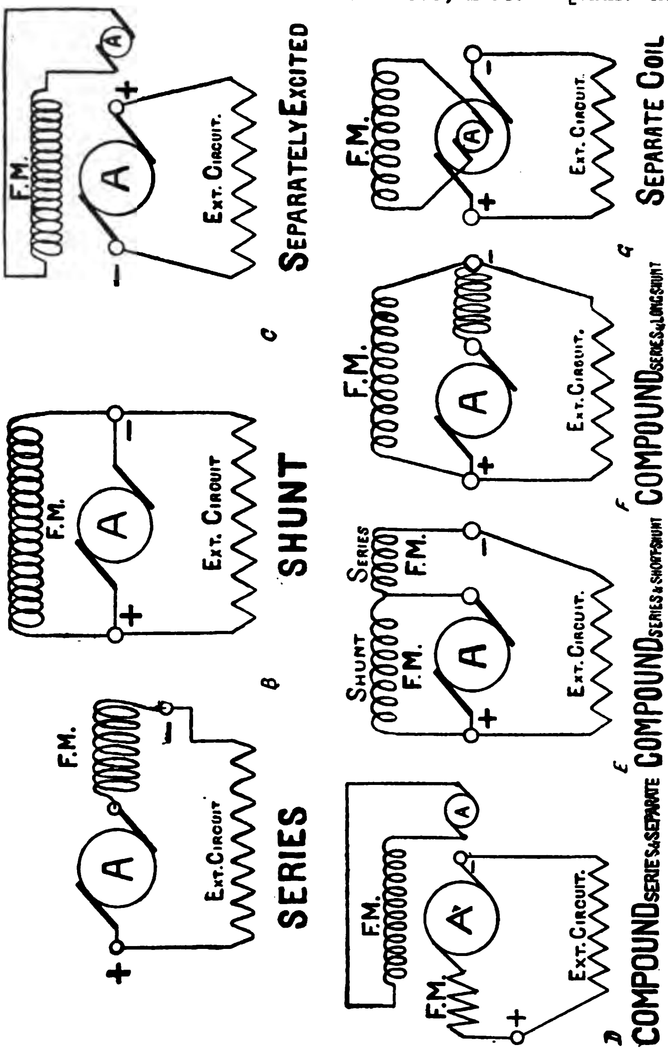


Fig. 174. Excitation of Dynamos.

(*e*) *Series and separately excited machine* (Fig. 174D). In such a machine the F.Ms. are wound with two distinct coils. One of these coils is connected up in series with the armature and the external circuit, as in the case of the simple series machine; while the other is in circuit with a small auxiliary dynamo or exciter.

(*f*) *Series and short-shunt machine* (Fig. 174E). In this case there are also two sets of coils on the F.Ms. One is of thick wire, and is in series with the external circuit, and consequently carries the main current; while the other is of fine wire, joined up as a shunt to the armature.

(*g*) *Series and long-shunt machine* (Fig. 174F). This method is very much the same as that just described, except that the shunt coil shunts not only the armature but also the series coil; hence the term *long-shunt.*

(*h*) *Separate-coil machine* (Fig. 174G). In such a machine, separate coils on the armature, which are joined up to a special commutator, furnish the current for the field magnets.

By this last method it will be seen that an alternator may be made to excite itself. Such machines, however, are not in extensive use.

Dynamos excited by either of the methods *A*, *B*, *E*, *F*, or *G* (Fig. 174), are termed *self-exciting machines.* The way in which a dynamo is to be excited depends

upon various circumstances, and will be considered later on as the question arises. The method in which a new dynamo is first excited was explained in § 155.

170. Action of the Ring Armature. In Fig. 175 is represented the effect which the insertion of the core of a ring or cylinder armature has in distorting the magnetic field, which otherwise would pass straight across from pole to pole. In § 158 it was stated that

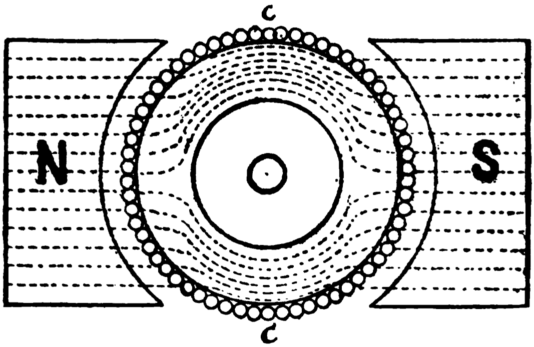


Fig. 175. Magnetic Field of Two-Pole Dynamo, with Ring or Cylinder Armature.

one disadvantage of a ring armature lay in the fact that the inside turns of the coils were not instrumental in generating E.M.F., for they do not cut any lines. This will be clear from an inspection of the figure, where it will be seen that practically no lines pass through the hollow part of the core. If they did they would cause a counter or reverse E.M.F. to be induced. In ordinary *closed-coil armatures* (ring or drum) it will be remembered that the end of one coil is connected

with the beginning of the next, and so on all round, so that there is a complete closed circuit through the coils of the armature. In fact, a ring or cylinder armature may be considered to be simply a ring of iron wound round with a coil of wire, the ends of which are joined together; the commutator segments being

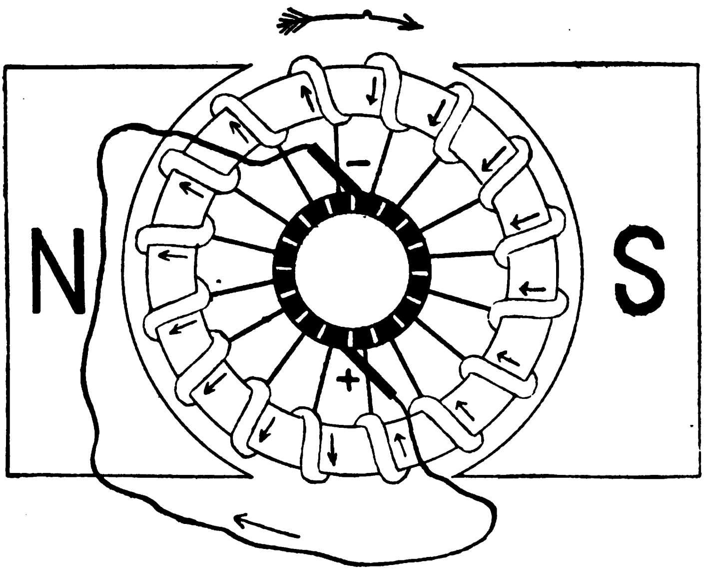


Fig. 176. Circulation of Current in a Ring Armature.

connected at equidistant points all round the coil, thus subdividing it. In Fig. 175 *c*, *c* represent the outer turns of the wire coils, the inner turns being omitted. As the armature revolves, the conductors on the right-hand side, which are descending across the field, have

E.M.F. induced in them in a direction from back to front; while those on the other side, which are ascending across the field, have E.M.F. induced in them from front to back. A few of the turns at top and bottom, which are merely slipping along but not cutting the lines, will have no E.M.F. induced in them. This action will be understood more clearly from Fig. 176, where a ring armature with a few coils, a commutator, and brushes, is shown. It will be clear that every coil on the armature has the direction of its E.M.F. changed twice every revolution. At any instant, the current due to the E.M.F. in all the coils on the right-hand side is flowing downwards, and such also is the direction of the current in the other half. In fact, the two halves of a ring armature, when revolving in the field, may be compared with two equal batteries with their + and − poles joined together (Fig. 177). When the batteries are left to themselves, no current at all will flow; but if the points where they are opposed to each other be joined by a wire, they will act together in parallel with each other, and send a current round the circuit. Just so with an armature, if the brushes do not press on the commutator, the E.M.F. in one half of the armature will always be opposing the E.M.F. in the other half, and no current will flow round it. But if the outer circuit be connected, through the medium of brushes and commutator, with those parts of the armature where the E.M.Fs. of neighbouring coils oppose, the two halves of the armature will act together in parallel, and a current will flow round the external circuit.

In comparing the two halves of a ring armature with two batteries in parallel (Figs. 176 and 177), it must be pointed out that the comparison is not a perfect one, as the coils are not generating the same E.M.F. Consider, for instance, the right-hand side of the armature; the two coils just opposite the *S* in the figure are generating the greatest E.M.F., as they are in the best

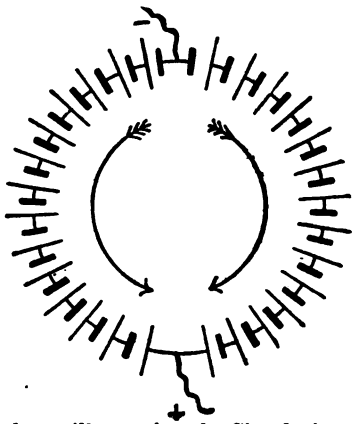


Fig. 177. Analogue illustrating the Circulation of Current in a Ring Armature.

position in the field; the coils immediately above and beneath these are generating less E.M.F., the next coils above and below still less, while those at the top and bottom are not generating any, as they are cutting no lines of force.

171. Lead of Brushes. The points on the commutator where the brushes should press are called the *neutral points.* If the field remained as in Fig. 175,

these points would lie on a diameter, called the *diameter of commutation*, at right angles with a straight line joining the N. and S. poles of the F.Ms., supposing the ends of the coils to be connected to the commutator segments immediately opposite them, as in Fig. 176. In practice, however, it is found that the armature, which virtually becomes a magnet when a current is flowing round it, and has consequently a magnetic field of its own, reacts

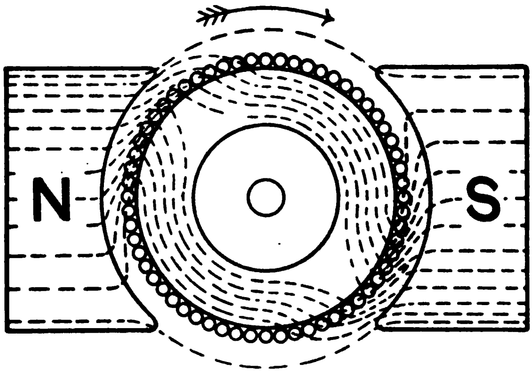


Fig. 178. Distortion of Dynamo Field.

on and distorts the field due to the field magnets. The effect of this distortion is to twist the field in *the same direction as the armature is revolving*, as shown in Fig. 178; consequently the neutral points on the commutator, and the diameter of commutation are likewise twisted round. The brushes have therefore to be moved forward, otherwise sparking would occur (§ 175): the amount of this movement is called the *lead* of the brushes, or the *angle of lead*.

172. Winding of Drum Armatures: Connectors. An ordinary ring or cylinder winding is perhaps the simplest of all windings, and will have been clearly understood from §§ 157 and 158. The winding of a drum armature is more complicated, and has been briefly discussed in § 159. Fig. 179 represents the back view of the winding of a simple drum armature with only three coils, each of two turns, for the sake of

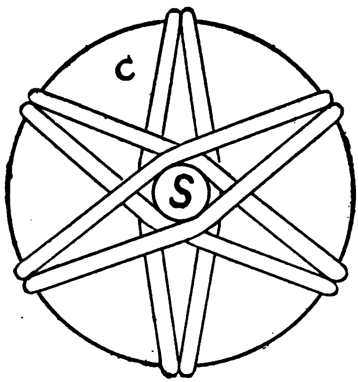


Fig. 179. Back view of simple Drum Armature.

clearness. S is the shaft, and C the end core-plate. Some drum armatures, generally for small machines, are even now wound in this way. In such a method of winding, where the coils overlap each other at the ends, it is evident that parts of coils having a considerable difference of potential approach very close to each other; and it thus becomes necessary to see that each overlapping layer is well insulated from the other, a

matter of some difficulty. The replacing of a burnt out or otherwise damaged coil on an armature wound like this is a tedious matter, as it necessitates the unwinding of all the coils which happen to overlap the injured one.

When, as is often the case, the coils of a drum armature consist simply of one turn, the "coil" may be made by running a rigid copper wire or bar along the top and bottom of the core, and making the connection at the back by means of a *connector*. The employment of these connectors is advantageous for two reasons: (i.) when an armature is designed to generate heavy current its conductors must be very thick, and the ends of these conductors could not well be bent round the end, as shown in Fig. 179, but can easily be joined together behind by means of connectors. (ii.) Their employment enables the end connections to be much better insulated, as the conductors at different potentials do not come so close together as in ordinary winding. Fig. 180 represents the back view of an armature provided with these connectors. The arrangement of the connections here shown is only one of very many methods which vary considerably in detail, but have a common object in view. This particular method is due to Messrs. Crompton & Swinburne. $C\,C$, $C^1\,C^1$, $C^2\,C^2$, etc., are the ends of the conductors of the armature. The end of one half of each "coil" just overlaps and turns over the top of the core disk, while the corresponding half to which the first half is to be connected is bent at right angles, and the two are

connected by a curved metal connector of copper or phosphor-bronze, *c c*. Thus *C C* represent a pair of conductors connected across by the connector *c c*. The conductors C^1 C^1, C^2 C^2, C^3 C^3, C^4 C^4, C^5 C^5, are

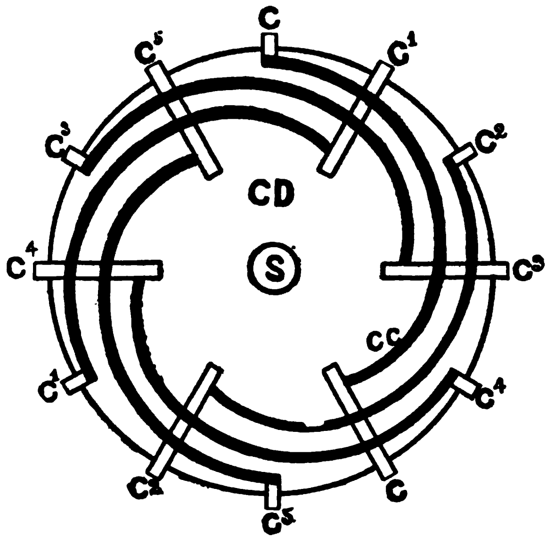


Fig. 180. Connectors of Drum Armature.

similarly joined. *S* is the shaft, and *C D* the end core-disk.

It will be noticed that the conductors immediately opposite are not joined together. Thus *C*, instead of being connected with C^5, as one might expect, is connected with *C*. This is for convenience in construction, and does not seriously affect theoretical conditions,

though possibly it has the effect of slightly prolonging the E.M.F. in each coil.

In the "*former*" *method of drum winding* each coil is separately wound on a special former, and its ends bound round with insulating tape, after which it is laid in position on the armature. A single coil and a complete armature wound on this principle, which is now very widely adopted, are shown in Figs. 201 and 202. Any coil can be easily removed.

173. CROSS-CONNECTION OF FOUR-POLE ARMATURES. In four-pole machines, sections of field magnets of which were shown in Figs. 172 and 173, the E.M.F. in each coil of the armature is changed four times every revolution, instead of twice, as is the case with any coil of a two-pole machine. Consequently there are two diameters of commutation, and four brushes would appear to be necessary, 2 + and 2 −. Four brushes were employed in the early four-pole machines, but now only two are used, the commutator segments being *cross-connected.* Referring to Fig. 181, it will be seen that any pair of diametrically opposite coils are at any moment undergoing precisely the same inductive action. Thus the coil C is just approaching a N. pole, and so also is the opposite coil C^1; the coils C^2 and C^3 are just leaving the N. poles and approaching S. poles; and so on all round the armature. The two theoretical diameters of commutation are indicated by the dotted lines $d-d-$ and $d+d+$. The current might be collected from such a machine by putting two brushes top and bottom (which would be +), and

two more right and left (which would be −), and connecting the respective pairs in parallel. But the same end is attained by connecting each commutator segment with the one diametrically opposite to it, and

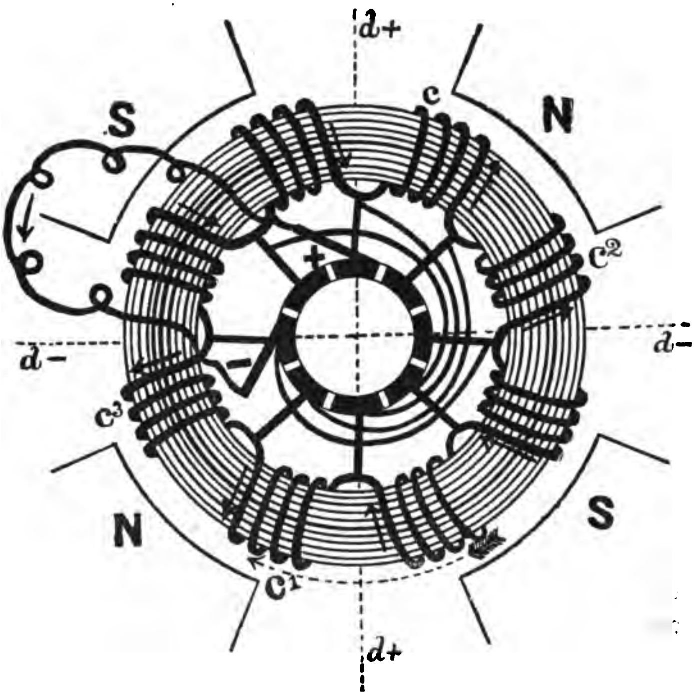


Fig. 181. Cross-connection of Four-Pole Armature.

employing only one pair of brushes, placed 90° apart, as shown. This cross-connection of the commutator segments is made by means of connectors very similar

to those employed for the purpose explained in § 172 Of course in a four-pole machine, as in any other, the field is distorted by the reaction of the armature, and a lead has to be given to the brushes; but whatever lead be given, they must always be 90° apart. In a six-pole machine there are three diameters of commutation, but by cross-connecting the armature coils, two brushes suffice, which are placed 60° apart: otherwise, six brushes would be necessary.

174. OPEN-COIL ARMATURES. An *open-coil armature*

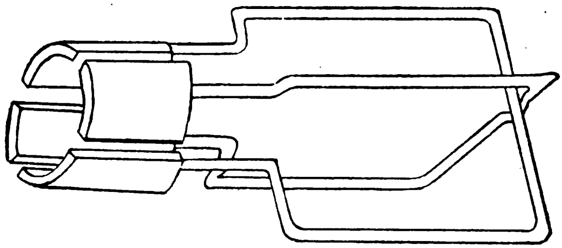


Fig. 182. Simple Open-Coil Drum Armature.

may be distinguished from an ordinary armature by the fact that the ends of the coils, or at least one end of each, terminate at separate commutator segments, and there is therefore no complete circuit through the coils of the armature. A simple open-coil armature with two coils is illustrated in Fig. 182, while Fig. 183 shows another form in which diametrically opposite coils on the armature are joined in series to form one coil. Open-coil armatures are employed in direct-current machines for developing high E.M.F., such as is necessary for arc lighting, when the lamps are

arranged in series; these machines giving an E.M.F. as high as 3,000 volts or more. In an open-coil armature, the currents are taken from the coils while the latter are in the position of maximum activity, and they are cut out of circuit while inactive. Open-coil armatures may be wound on either the ring or

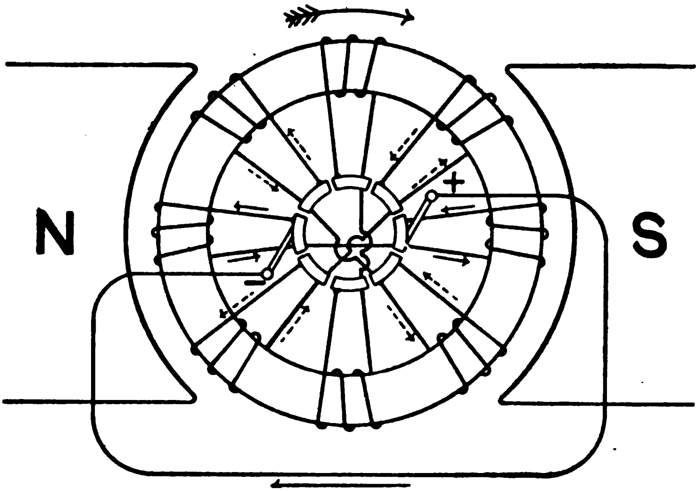


Fig. 183. Open-Coil Ring Armature.

drum principle, but in the former case diametrically opposite coils are joined in series, as shown in Fig. 183. Fig. 182 is a simple example of an open-coil drum armature.

The only open-coil dynamo in use in this country is the Brush Arc Dynamo, which is described in § 196.

175. Sparking of Dynamos. In an ordinary or closed-coil machine, when the brush is in the act of passing from one commutator segment to another, for a short interval it is in contact with both, and so short-circuits the coil connected between them. Now if the coil is still active, *i.e.*, if it is still cutting the field and consequently generating E.M.F., a comparatively strong current will flow round the coil and the short-circuiting brush, and at the moment the brush un-short-circuits the coil a spark will occur, which will heat and tear away the points of contact between the brush and the commutator segment, besides wasting energy. To prevent sparking, it is first necessary to see (in a 2-pole machine) that the brushes are pressing on diametrically opposite points of the commutator, and then move the rocker until the proper "lead" is found, *i.e.*, until the brushes touch the commutator segments a little in advance of those connected with those coils which are passing through the neutral position, which is best done by moving the rocker till there is no sparking at the brushes.

This is the principal cause, effect, and means of prevention of sparking in dynamos.[1]

* 176. Construction of Commutators. The con-

[1] Special means of getting rid of the armature reactions of dynamos have been proposed by Swinburne (reversing pole-pieces), by Sayers (compensating armature coils), and by Ryan (auxiliary F.M. coils), etc. These, however, require elaborate treatment to make their application intelligible, and cannot therefore be considered in this work.

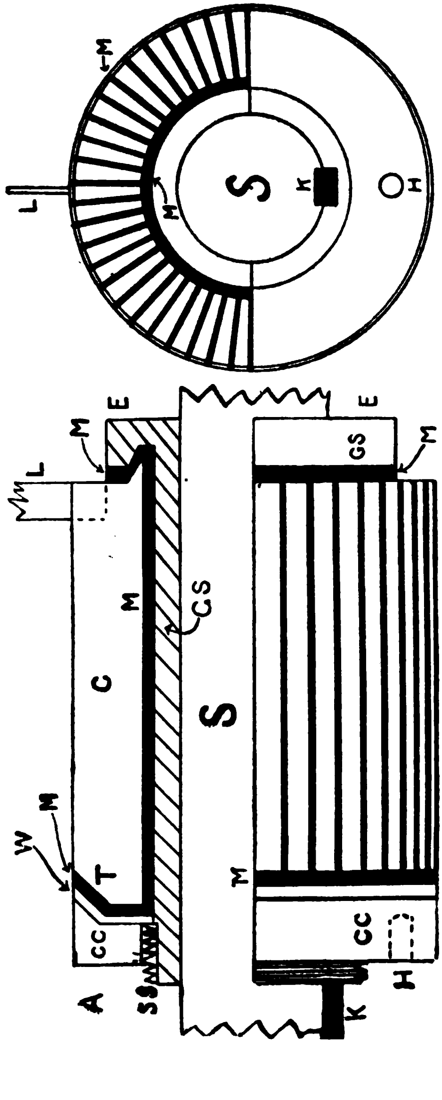


Fig 184. Construction of Commutators.

bars are insulated from the rocker by the vulcanised fibre washers *V V*. *B B B B* are the brush-holders, with the brushes removed. These are free to rotate upon the brush-holder bar, and by means of springs, when in position on the commutator, cause the brushes to press against the latter. It will be noticed there are four brush-holders, two + and two −. If a wide brush were used, it would not be an easy matter to adjust it, or, when adjusted, to keep it bearing evenly upon the commutator. It might be touching at the middle only, or at the two sides only, or it might be tilted up on one side. This would result in sparking, and very uneven wear of the commutator. By having two brushes, which act, and can be slipped along the bar independently of each other, any uneven wear of the commutator can be provided against, and much better contact made. Large machines have as many as three, and sometimes four or more independent brushes (Figs. 212, 213, and 214). It is well that each brush-holder *B* should be provided with a flexible lead connecting it with the end of the brush-holder bar, or with the terminal of the machine, as the contact between holder and bar is not always good.

Figs. 186 and 187 give elevational and perspective views of the rocker, brush-holders, and brushes used on some of Crompton's direct-current machines (§ 185). The rocker is in two portions, which are held together by the bolt and nut *B N*, and the tightening screw *T*. The leads are sweated to thimbles fixed by means of bolts to the blocks *B*, *B′* on the brush-holder bars, a hole for which purpose will be seen

in *B′*. *C* is the commutator, and *A* the end of the armature. *R* is a ring corresponding with *CC* in Fig. 184, and the end of the shaft is just shown. The brush-holder bars *BHB* are screwed at one end, and passing through insulating washers (shown black) are secured to the rocker by the nuts *n n′*.

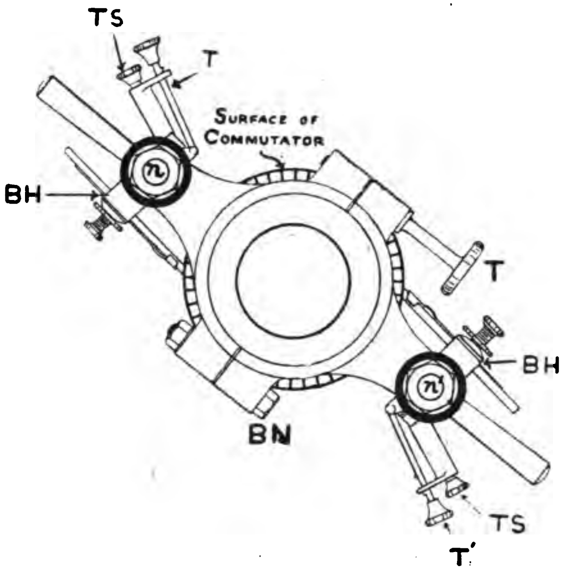


Fig. 186. Crompton Rocker and Brush-Holders.

The brush-holder *BH* is fitted with an adjustable spiral spring enclosed in a tubular box. This spring pulls the holder round the brush-holder bar, so as to bring the brush to bear on the commutator, and its tension may be adjusted by the thumb-screw *TS*. *T*

is the hold-off trigger. If this is pushed in, it rotates *B H* and lifts the brush from the surface of the commutator; a notch in the shank of *T′* locking it in the "off" position. The handles of *T′* and *T S* are of vulcanite.

Fig. 188 illustrates the construction of the *direct-*

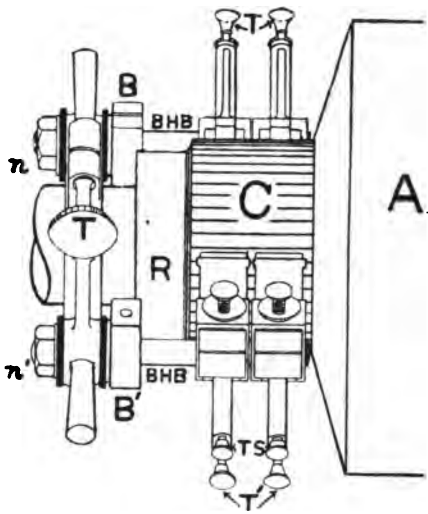


Fig. 187. Crompton Rocker and Brush-Holders.

thrust brush-holders formerly used on some of Mavor & Coulson's machines. Though this type has since been discarded by this firm, the illustrations and description are retained as being of general interest.

Fig. 188 gives sectional elevation and plan (part section). *R* is the rocker, and *C* the commutator. The

square-shaped brush-holder frame $B\,F$ is bolted at one

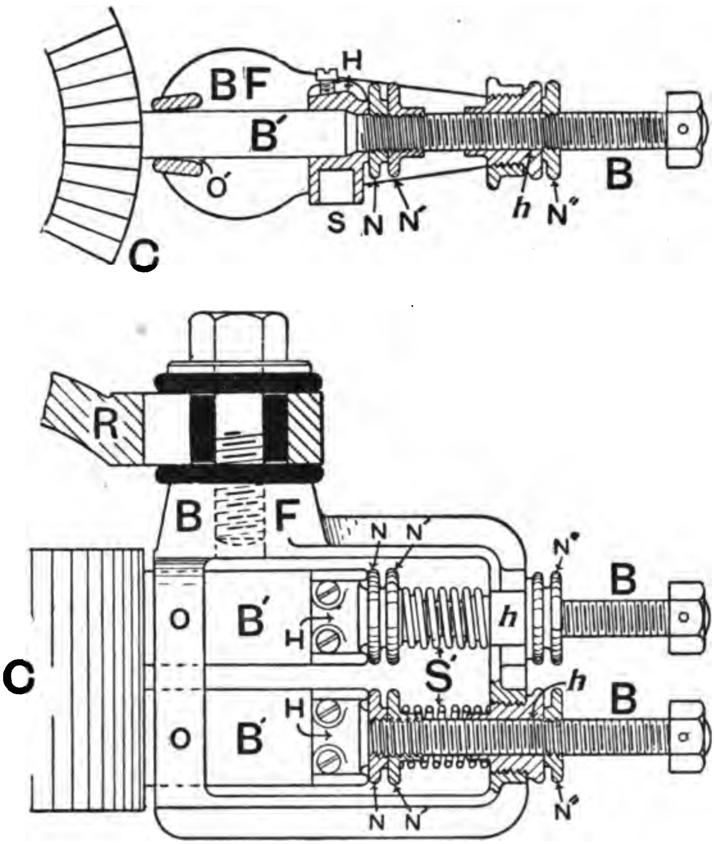


Fig. 188. Direct-thrust Brush-Holders.

side into the end of the rocker, and is insulated therefrom by the vulcanite washers and collet (shown black).

The brushes (either copper gauze or carbon) are illustrated at *B′*. The actual holders are at *H*, the brush being secured therein by a couple of screws. The underside of the holders terminate in sockets *S*, in which the leads are soldered. The front ends of the brushes pass through openings *O* in the front of the frame. These openings are slightly tapered, so as to allow of the brush being easily inserted, as shown at *O′*. To *H* is fixed a long screwed bolt *B*, which passes through a smooth free hole in the frame at *h*. Tapped on to *B* are three thumb nuts *N*, *N′* and N″. A helical

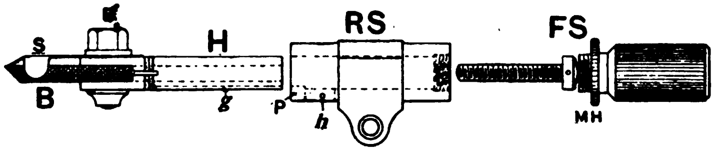


Fig. 189. Jackson Brush-Holder (details).

spring *S′* is threaded on to *B* between the frame and *N′*, and when *N″* is loosened, the spring forces the brush on to the commutator. By screwing *N″* up, the brush is withdrawn from the commutator. The tension of *S′* is adjusted by *N′* and *N*, which serve to lock each other in position.

One form of brush-holder used on some of the machines built by Messrs. P. R. Jackson & Co., is clearly depicted in Figs. 189–193. The parts of the brush-holder proper are shown apart in Fig. 189. *B* is the copper gauze or carbon brush, and *S* a sheet steel spring-piece which serves to steady its extremity.

This spring is also shown in Figs. 191 and 193, but not in Fig. 192. *B* and *S* are firmly secured to the holder *H* by means of the short bolt *B′*. A groove *g* is cut on the underside of the shank of *H*, and this shank is drilled and tapped to take the end of the feeding screw *F S*. The milled head *M H* runs free on *F S*, but is held fairly firmly by the bent washer shown, so that when *M H* is screwed tightly into the

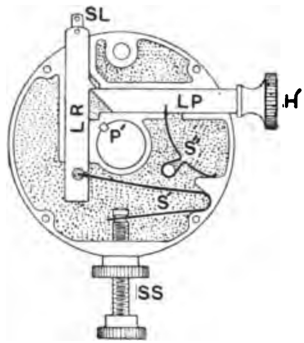


Fig. 190. Jackson Brush-Holder. (Spring case.)

end of the rocking sleeve *R S*, *F S* is not likely to be rotated by the vibration of the machine. When *H* and *F S* are screwed together in *R S*, a pin *P* fits loosely in the groove *g*, so that *H* is permitted such slight rotation as will enable the brush to set evenly on the commutator.

The interior of what may be called the "spring case" is shown in Figs. 190 and 191. This fits tightly on to the brush-holder bar, and is secured thereto by a set screw passing through a boss at the side of the

case. This set screw and boss have recently been

Fig. 191. Jackson Brush-Holder.

added, and are only shown in Fig. 193, which is a more recent illustration than the others. Here also it

will be noticed that the brush-holder and spring case are connected by means of a flexible spring, which is

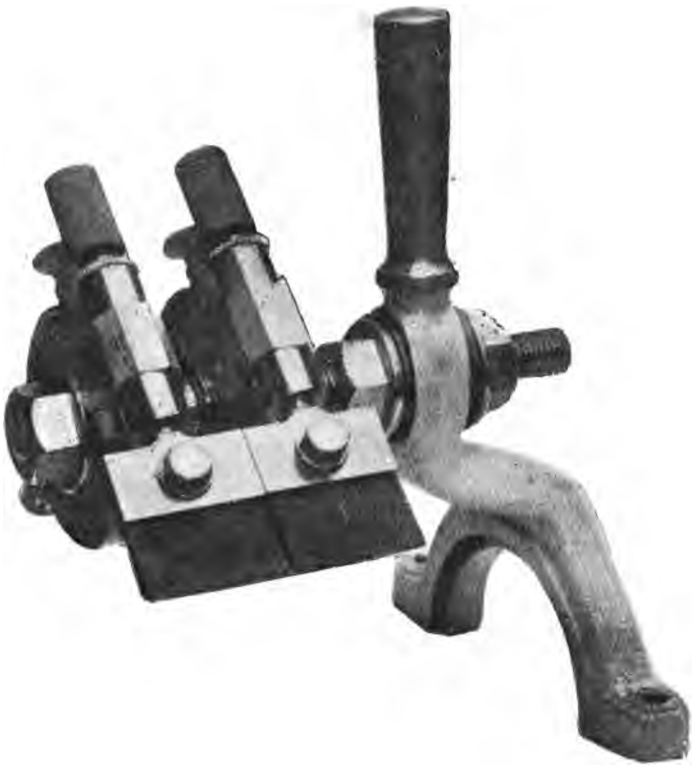


Fig. 192. Jackson Brush-Holders and half of Rocker.

of copper, and which has been added to render the contact between the two more certain.

A brush-holder bar with two brushes in position and half the rocker is shown in Fig. 192. The spring case is in one casting, with milled passages in which travel respectively the link rod *L R* and locking piece *L P*. When *R S* (Fig. 189) is screwed in position on the spring case, *L R* is linked to the front of *R S* by the steel link *S L*, which is held by a pin passing through the hole *h*

Fig. 193. Jackson Brush-Holder.

in *R S*. A steel spring *S′*, the tension of which may be adjusted by the set screw *S S*, pulls *L R* downwards so that the brush is brought to bear on the commutator with any desired pressure; while, as it wears away, it may be fed forward by *F S*. By tilting *R S* the brush is taken off the commutator, and "locked off" by *L P*, which is forced inwards by the second steel spring *S″*. The brush is released by pulling out the

handle H', which like that of $F\,S$ is of vulcanite. $L\,R$ is shown in the locked position in Fig. 190, and in the unlocked position in Fig. 191.

* 178. BRUSHES. Brushes are made of copper gauze, foliated copper, or carbon, a special copper alloy being sometimes used instead of pure copper. Fig. 194 illustrates a gauze brush. The core is composed of strands of fine twisted copper or alloy wire, plaited and compressed and encased in a covering of woven metal, which is shown cut open in the figure

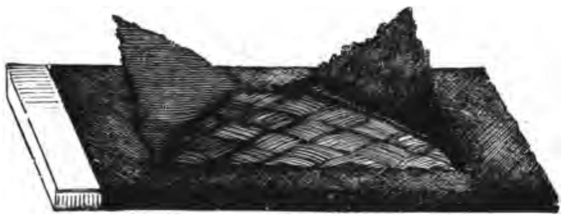


Fig. 194. Gauze Brush.

in order that the interior may be seen. The foliated brushes are built up of exceedingly thin sheets or leaves of metal about the thickness of tissue paper, and compressed tightly together.

For motors and dynamos, but especially for the former, carbon brushes are widely used, these being set more or less end on to the commutator, to allow of its turning in either direction. A simple form of carbon brush-holder is depicted in Fig. 195; and, as already explained, the holder illustrated in Fig. 188 is also designed for carbon brushes. The use of car-

bon for this purpose, in dynamos as well as motors, is now very general.

179. CONSTANT-POTENTIAL AND CONSTANT-CURRENT DYNAMOS. Depending upon the condition of the outside circuit, dynamos may be required to maintain either a *constant potential* between the supply mains, or a *constant current* round the circuit, even though the latter may alter considerably in resistance. Thus,

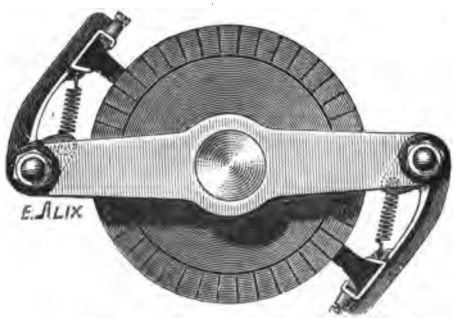


Fig. 195. Simple Holders for Carbon Brushes (*Le Carbone*).

in parallel incandescent and arc lighting and power work, dynamos must maintain a constant potential between the + and – mains, whatever the demand for current may be. In series arc lighting it is just the reverse, the dynamo having to keep the current constant through a varying resistance caused by the switching in and out, and fluctuations in the positions of the carbons of the lamps. Series arc lighting, however, is seldom resorted to nowadays, so that there is

little use for constant-current machines. One form of such, nevertheless, is illustrated in § 196. The regulating effects of series, shunt, and compound winding (§ 169) will be explained in Chap. X. (Vol. II.); and the theory and working of direct-current dynamos will also be further considered therein. In the next chapter several well-known direct-current machines are described in detail, and many points in dynamo and motor construction, not here dealt with, are considered in conjunction with the machines embodying them. In Vol. II. motors will have a chapter to themselves.

CHAPTER VIII.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. What is a dynamo?

*2. There are two great classes of dynamos; name them.

*3. Mention the essential parts of a dynamo.

*4. In what respects does an alternator differ from a direct-current dynamo?

*5. Sketch and describe the action of a simple alternator.

*6. Sketch and describe the action of a simple direct-current dynamo, having one coil of two turns for an armature.

*7. *Define in your own words:* commutator, brushes, collector, F.M., armature.

8. Upon what does the E.M.F. generated by an armature depend?

*9. Why are armatures generally provided with iron cores?

*10. Give a sketch of a shuttle armature, showing clearly the core, the coil, and the commutator.

*11. *Define:* self-exciting dynamo, brush-holder, pole-piece, spider, rocker.

*12. Name and briefly describe the different kinds of armature.

*13. Sketch and explain the construction of a gramme or ring armature, and say in what respects it differs from a cylinder armature.

14. Explain clearly the difference between a ring and a drum armature.

*15. How is the core of a ring or cylinder armature fixed to the driving shaft?

16. *Define:* idle wire, core-plate, eddy current, salient pole, consequent pole, excitation of dynamos.

*17. Describe the construction of a simple drum armature.

*18. Explain fully the importance of fixing as rigidly as possible, the armature core to the shaft, and the conductor to the armature core.

19. Sketch three methods of mounting the core of a drum armature on the shaft.

*20. Describe various methods of driving armature conductors.

21. How do you account for the great resistance experienced in rotating the armature of a dynamo supplying current?

22. Give ideal sketches of two kinds of disk armature.

23. Say what you know about the winding of armatures, as far as regards the number of coils size of wire, and number of turns on each coil.

24. In building a large dynamo, would you use a drum or a ring armature? Give reasons.

25. Say what you know about, and give reasons for, the lamination of armature cores.

*26. Name the principal forms of F.M.

*27. Is there any difference between a two-pole and a double-magnet machine?

28. Sketch four types of F.Ms. of single-magnet dynamos, and indicate the path and + direction of the magnetic flux by dotted lines and arrows.

29. Sketch three types of F.Ms. of double-magnet machines, and indicate the path and + direction of the magnetic flux by dotted lines and arrows.

30. Sketch two types of F.Ms. of four-pole, and one type of

multipolar machine, and indicate the path and + direction of the magnetic flux by dotted lines and arrows.

*31. Describe and compare the series and shunt methods of winding dynamos.

*32. Describe the different kinds of compound machines.

33. *Define:* magneto-dynamo, separately excited dynamo, self-exciting dynamo, separate-coil dynamo.

34. Describe fully, in your own words, the action of the ring armature.

35. How may the action of a ring armature be compared with that of two batteries in parallel?

36. What would be the effect of shifting the brushes of a ring or cylinder armature dynamo 90° round from their proper position?

37. Give a hand sketch showing to half of the natural size a longitudinal and a transverse section of a modern armature wound on the gramme system? the sketch to include the mechanical attachment of the armature core to the shaft. External diameter of armature core, 9 in.; length, 10 in. You need not calculate any part, but simply show by your sketch what you consider, from a practical point of view, the correct proportions of the different parts. Do not show every wire, but indicate the total space to be occupied by the winding. [Ord. 1892.]

*38. Describe in detail how you would true up the commutator of a dynamo. [Prel. 1898.]

*39. Why is it necessary to laminate the iron core of a dynamo? Show, by means of sketches, in which direction you would laminate the core (*a*) of a flat ring armature in which the magnet poles were presented to the sides of the ring, (*b*) in a cylinder armature in which the magnets were presented to the cylindrical surface. [Prel. 1900.]

40. A direct-current dynamo, which gives 300 amperes at 110 volts, has a drum armature 14 inches diameter containing 120 bars; describe, with sketches, the commutator and brushes you would use, giving approximate dimensions, and state the nature of the material you would employ for the commutator and for the brushes respectively. [Ord. 1900.]

*41. Make a diagrammatic sketch of a shunt-wound continuous current dynamo with ring armature, and indicate clearly the direction of flow of the current in each part of the machine. [Prel. 1901.]

42. *Define:* lead of brushes, angle of lead, diameter of commutation, neutral points on a commutator.

43. What difficulty in the winding of drum armatures has led to the employment of connectors?

44. Sketch the back view of an armature provided with connectors, and explain the arrangement.

45. Sketch a drum armature showing the connections and windings for 24 conductors on the outside. Sketch also any methods of end connection for drum machines in ordinary use. [Ord. 1895.]

46. Describe some system of drum winding which enables a coil to be removed without disturbing the others.

47. Show clearly why in a four-pole machine, if the commutator and coils were connected in the ordinary way, four sets of brushes would be necessary.

48. Explain the method of cross-connecting a four-pole armature.

49. In what respects does a closed-coil armature differ from an open-coil one?

50. What are the advantages of open-coil armatures, and under what circumstances are they used?

51. Mention some of the causes of sparking in dynamos, and their remedies. [Ord. 1893.]

52. Give full-size hand sketch of a commutator, 6 in. diameter, 4 in. face, showing in section how the plates are supported and insulated. [Ord. 1894.]

53. Sketch a modern form of brush-holder arranged for taking a brush $1\frac{1}{2}$ in. wide by $\frac{5}{16}$ in. thick. Make the sketch free-hand, full size, and roughly to scale. [Ord. 1893.]

*54. What are the essentials of a good brush-holder?

55. Sketch some form of brush-holder not mentioned in this book.

*56. Describe various kinds of brushes.

*57. When is it generally necessary to use compound brushes?

*58. What kind of brush would you use for a motor?

59. Explain the difference between constant-potential and constant-current dynamos.

60. Give a sketch, or sketches, to illustrate the winding of a drum armature for use in a four-pole field. [Ord. 1896.]

61. Sketch a modern end-connection system for a drum armature with 32 commutator pieces. [Ord. 1897.]

CHAPTER IX.

The figures refer to the numbered paragraphs.

* 180. INTRODUCTION: DIRECT-CURRENT DYNAMOS. As most dynamo machines may be used either as generators of E.M.F. (dynamos), or as convertors of electrical energy into mechanical energy (motors), they are often, as in this chapter, called simply *machines*; except in cases where a machine is intended for use only as a dynamo, or only as a motor. The term *generator* is now frequently used to denote either a direct or alternating current dynamo. As regards its method of excitation, almost any kind of direct-current machine may be either series, shunt, or compound wound, to suit requirements.

The machines described in the present chapter are

by well-known makers, but there are, of course, many others equally good of which no mention is made, for want of space.

It should be borne in mind that nearly all makers build both large and small machines of varied pattern to suit any particular work or output. Thus small machines are almost invariably of the two-pole type; while for large outputs multipolar forms are employed. For instance, although in § 183 we illustrate a simple overtype machine, Messrs. Thomas Parker, Ltd., make various other kinds.

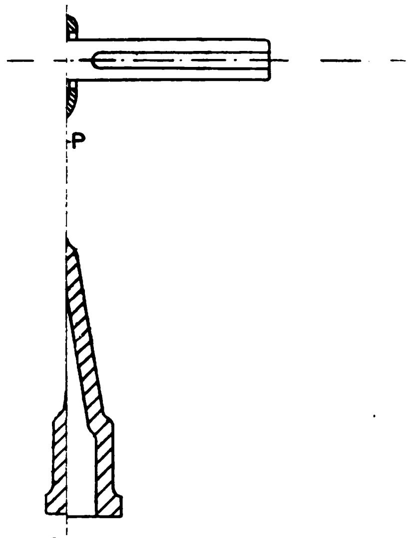
An *overtype* machine is a two-pole one in which the field magnet is placed with its poles uppermost, as in Figs. 200, 208, etc. This form was primarily adopted in order to do away with the likelihood of the lines of force leaking through the bed-plate. On the other hand, especially with a high-speed machine, it is mechanically bad to have the shaft raised very high. In the case of combined plant, where the dynamo is directly coupled to the engine, the machines are seldom overtype. (See Figs. 199 and 219.)

An *undertype* machine is a two-pole one with its poles below. All multipolar machines are termed *centraltype*; and some two-pole machines belong to this class, as for instance those shown in Figs. 209 and 211. The difference between *open-type* and *enclosed-type* machines is explained in § 194.

* 181. Sections of Overtype Field Magnets and of Armatures. Fig. 196 is a longitudinal section of an overtype machine, and gives a good general idea of

how dynamos of this pattern are built up. *B* is the bed-plate, the thickened part of which, *M Y*, forms the magnet yoke. *A C* is the drum armature core, the plates of which are compressed between two end pieces, one of which, *E P′*, bears against a thickened part of the shaft *S*, while the other *E P* is held in place by the distance piece *D P*. *C S* is the commutator section: and this should be studied in conjunction with that shown in Fig. 184. *S W*, *S W* are the spaces for the wire end-connections, and *E C* is an end cover which gives a finished appearance, the lugs of the commutator segments taking the place of an end cover at the opposite end. *M C* is one of the magnet coils, *P P* the pedestals, and *O W*, *O W* the oil wells. The bearings are of the old type with outside lubricators (not shown); and *oil throwers*, as alluded to in §§ 189 and 191, can be clearly seen. The shaft is grooved at its right-hand end in readiness for the fixing of the pulley.

A *smooth-core* armature is one in which the conductors are wound or laid on the surface of the iron core. In a *slotted* or *slot* armature the conductors are wound or fitted between projecting teeth or continuations of the core. These *Pacinotti teeth*, so termed from the name of their originator, drive as well as protect the conductors, thus making the armature very strong, and better adapted for heavy work and rough usage than the smooth-core design. The teeth also serve to decrease the interpolar magnetic resistance, and to dissipate any heat generated in the core. Armatures



[To face page 366.

of this description, which are very generally built nowadays, are also called *slot-wound* armatures.

A section of a two-pole overtype machine, showing the slotted core-plates and the method of attaching the latter to the shaft by means of three gun-metal "feathers," is given in Fig. 197. It will also be observed that the pole-pieces are split through from side

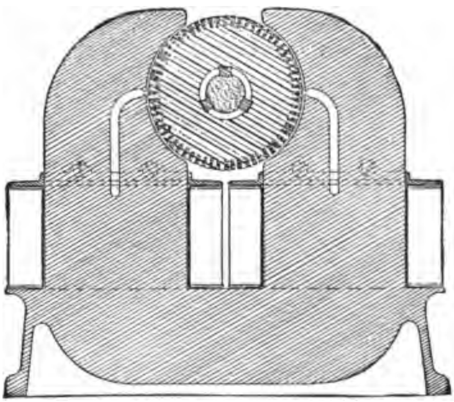


Fig. 197. Section of Machine with Slotted Armature and F.M. Cores.

to side, the slot in each pole running in the direction that the lines of force would take. This special arrangement was adopted by Messrs. Laurence, Scott & Co. as having the effect of stopping the generation of eddy currents in the poles, and the consequent waste of energy, and of giving additional ventilation without appreciably adding to the resistance of the magnetic circuit of the machine.

Sometimes the shaft is hexagonally shaped in the centre, and the core plates have corresponding hexagonal holes cut in them, and are then threaded on to the shaft (Fig. 167).

Most machines are now fitted with self-oiling bearings as described in § 189, so that the lubricator illustrated in Fig. 198 is somewhat old-fashioned. The figure is useful however as showing a spherical *self-aligning bearing*. This means that the bearing is mounted in a spherical "seating" on the cast-iron pedestal and cap, so that it is free to turn so as to place itself in perfect alignment with the shaft when the armature is first put in. The cap is then tightened down by bolts so as to grip the bearing in place.

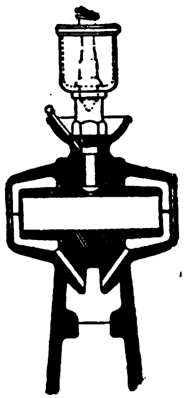


Fig. 198. Self-aligning Bearing.

A handy method of classifying machines is explained in § 187.

182. ALLEN, SON & CO.'S UNDER-TYPE ENGINE-COUPLED DYNAMO. Fig. 199 shows an undertype machine coupled direct to a vertical compound engine, by the above-named makers; a large fly-wheel being placed on the shaft between engine and dynamo to give steadiness in running. The holes in the periphery of this fly-wheel are for the insertion of a lever for moving the shaft round to the best starting position. The poles of the magnet are mounted on gun-metal *dis-*

tance pieces, to minimise the leakage of magnetic lines through the bed-plate, and the armature is drum wound, as will be perceived from the figure. The

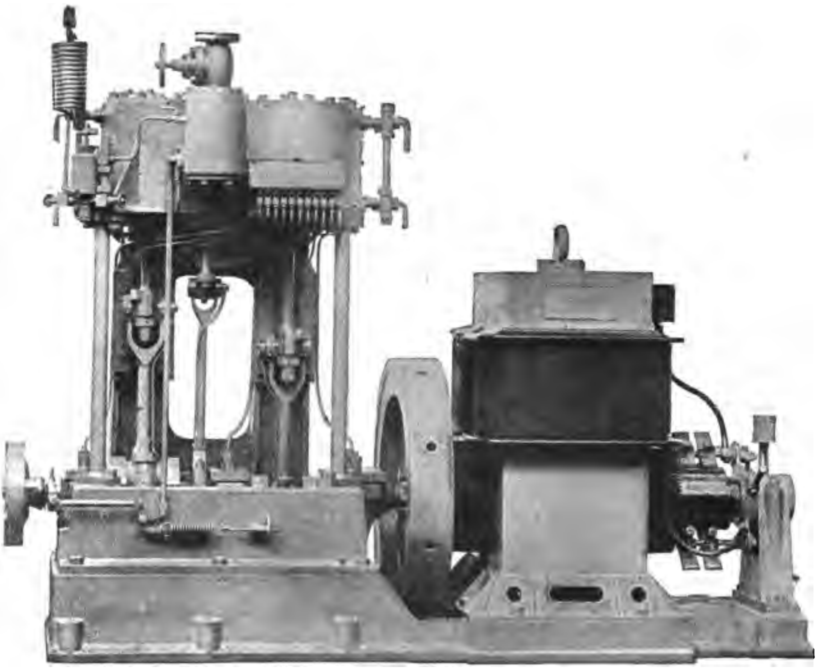


Fig. 199. Allen combined Undertype Dynamo and Engine.

engine and dynamo are mounted on a single cast-iron bed-plate, and there are four main bearings, those on the engine being lubricated from the sight-feed oil reservoir fixed on one of the cylinders. The tubes from

this reservoir lead also to various smaller bearings on the engine, as well as to the slipper faces. The fourth main bearing by the commutator has an ordinary sight-feed lubricator. By *sight-feed* is meant that the oil can be seen dropping into the bearing. Compact combinations of engine and dynamo such as these are essential in ship work, where every foot of space is valuable, the engine being supplied with steam from the ship's boilers, generally through a reduction valve.

183. Parker Overtype Machine (Fig 200). This machine is distinguished from all others by its hinged pole-pieces, an arrangement which enables the armature to be closely examined and cleaned while in position. With ordinary dynamos the taking out or replacing of the armature demands great care, as not only is damage from abrasion liable to occur in threading the armature into or out from the poles, but the shaft is likely to be put out of truth if one bearing is removed and the other not loosened. In the Parker machine the removal of the armature is easily accomplished. The two eye-bolts are withdrawn, and the brass shield-piece taken off, these being shown in the figure at the base of the dynamo. The rocker and top caps of the bearings are then removed, the pole-pieces thrown back, and the armature lifted straight out. Another advantage secured by this arrangement is that the machine may be placed in a more confined situation than would be possible if the armature had to be removed in the ordinary way. Then again, when the armature is removed, the magnet bobbins can

be slipped over the hinged pieces without difficulty. The bearings are of the self-oiling type, as described in § 189.

A special variation of the "former" method of drum winding alluded to in § 172, and whereby any coil

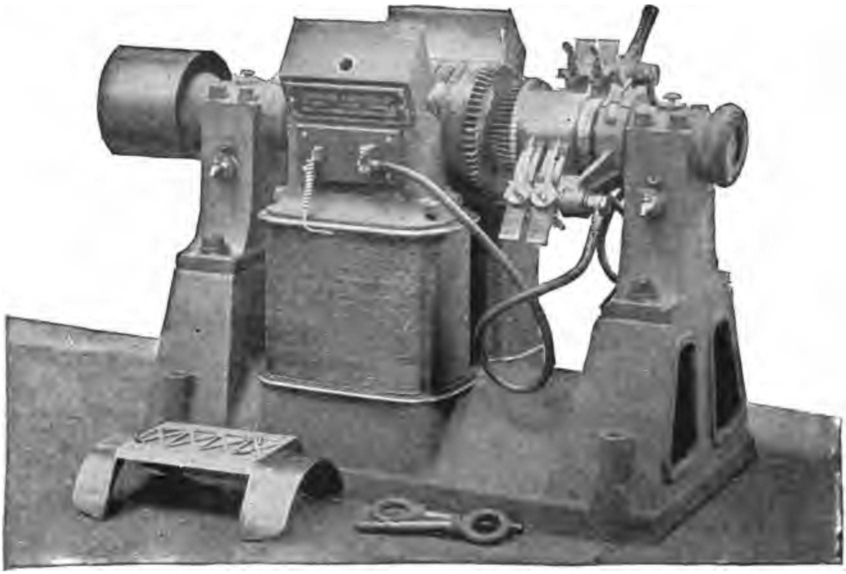


Fig. 200. Parker Overtype Machine.

can be easily taken from the armature and repaired or replaced, is adopted. Fig. 201 illustrates a single coil, and it will be noticed that in this particular case three parallel conductors are used in place of one single conductor. Each coil is wound separately on a

"former," and thoroughly insulated. This particular method of winding is termed the *Eickemeyer*, and, as

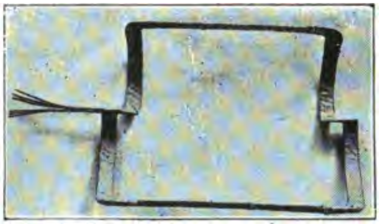


Fig 201. Armature Coil of Parker Machine.

will be noticed from the figure, differs from the ordinary "former" or *barrel winding* in which the two sides of the coil are in the same plane. A finished armature is shown in Fig. 202. Of course the binding wires, *B W*, must be undone before any coil can be removed from the armature.

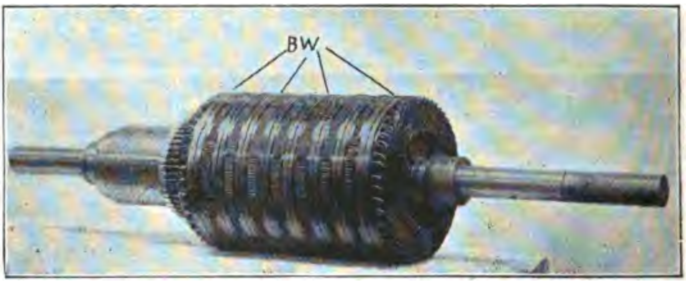


Fig. 202. Armature of Parker Machine.

Binding wires are used in almost all machines to hold the coils together, and to prevent them bulging out

under centrifugal force when the armature is rotating. They are made either of steel, phosphor-bronze, hard drawn brass, or German silver, the wire being tinned so that it can be easily soldered when in place. These

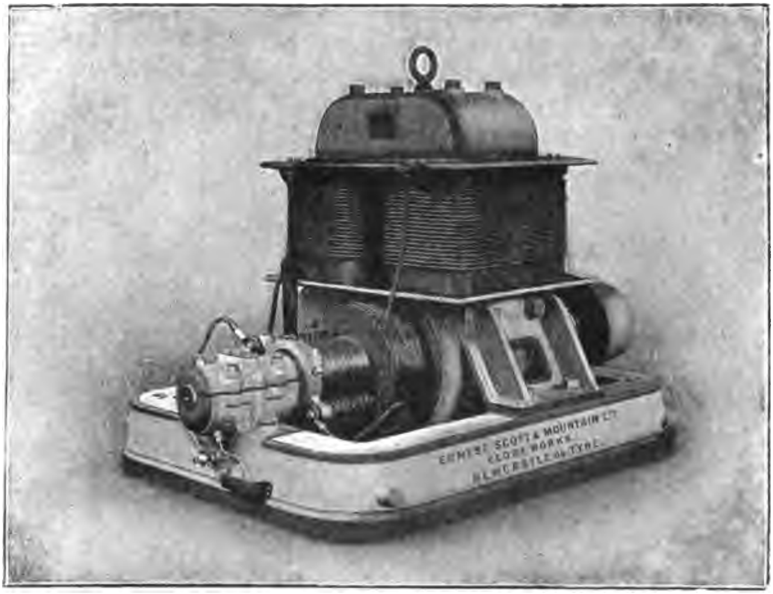


Fig. 203. Tyne Undertype Machine.

wires must be very strong, as they are of necessity small in diameter. They are wound on the armature over two thin bands of insulating material, usually vulcanized fibre and mica, the latter being uppermost.

* 184. Tyne Undertype Machine (Fig. 203). This

dynamo, built by Messrs. Ernest Scott and Mountain, is of the two-pole undertype. The design of the machine is good, inasmuch as the armature is placed as low down as possible and there is no need to use tall pedestal bearings, so that the vibration of the machine when running is very small.

The cast steel magnet is in three pieces, viz., two cores, each with a peculiarly curved pole-piece, and the top yoke. The magnet is fixed to the bed-frame by means

Fig. 204. Partly wound Armature of Tyne Machine.

of two stout gun-metal brackets, this metal being used to prevent the leakage of magnetic lines round the cast-iron bed-frame. Fig. 207 shows one of the removable magnet bobbins. The bearings, which are specially long, are of the usual self-oiling or ring-type (§ 189), and are fitted with overflow pipe and drain cock.

The armature is of the slotted drum type, as will be seen from Fig. 204, which shows one in process of winding. The peculiar shape of the coils will also be

noticed, these being *former-wound*, *i.e.* wound on frames or formers of the shape the finished coil is to have. The coil-ends ready for soldering to the lugs on the commutator are to be seen on the left. The shape of the coils is in fact somewhat similar to that shown in Fig. 201.

Fig. 205. Commutator of Tyne Machine.

Fig. 205 illustrates a commutator ready for fixing on the shaft, and the lugs for the connection of the coil-ends will be noticed. This figure should be compared with Fig. 184. Fig. 206 shows a finished armature.

These machines are shunt, series, or compound wound as required; that illustrated in Fig. 203 being

Fig. 206. Complete Armature of Tyne Machine.

compound wound. As a rule they are fitted with carbon brushes.

185. Crompton Overtype Machine. The upright double-magnet type of machine, long made by this firm, and having an iron section somewhat similar to Fig. 171c, but with straight pole-pieces, has now been discarded in favour of the simpler single-magnet overtype and undertype. The new overtype machine is illus-

Fig. 207. Magnet Bobbin of Tyne Machine.

trated in Fig. 208. Each F.M. core (of wrought iron or best mild steel) is made in one or two pieces, which are bolted to the yoke-piece cast on the bed-plate. The machine illustrated in the figure has each core in two pieces, the line of demarcation being only shown at the bottom, where they are bolted to the yoke-piece. At the top the poles are united by a non-magnetic cross-piece. All the armatures are drum-wound, the cores being built up of the softest annealed

charcoal iron discs. The commutators are of hard-

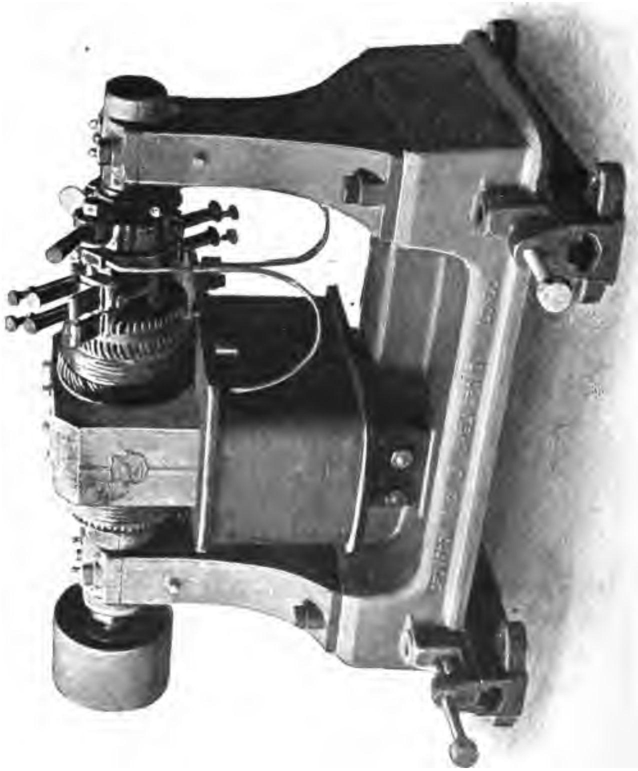


Fig. 208. Crompton Overtype Machine.

drawn copper, and the bearings self-oiling. These machines are said to have a very high efficiency.

The rocker and brush-holders of this machine were illustrated and described in § 177.

186. Brush Two-pole Centraltype Machine (Fig. 209). This machine has several distinctive features. The circular magnet cores are of wrought iron or steel, and are united at top and bottom by cast-iron yokes, each of which is in two pieces. The bottom yoke

Fig. 209. Brush Two-pole Centraltype Machine.

stands on four feet on the cast-iron bed frame and is bolted thereto, while the upper one carries the terminal board, the leads from the ends of the field winding passing thereto through holes in the pole-pieces.

The two parts of each yoke-piece are held together by a web at the sides, but are separated by a gap of one inch at the smallest point. This construction greatly reduces the effect of armature reaction,

and helps to produce very sparkless collection, which

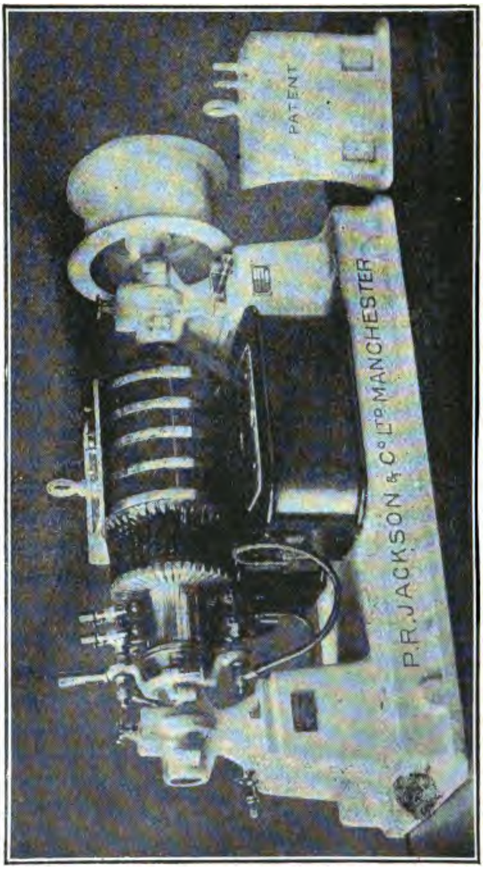


Fig. 210. Jackson Overtype Machine.

is one of the points of these machines. An additional

advantage in the use of cast-iron pole-pieces is that the considerably higher resistance of this material reduces the "eddies" in the pole-piece to a negligible amount.

The armature is built up of slotted discs, ample ventilation being allowed. It has a neat symmetrical winding put on by hand, formed coils not being used. The bearings are of the usual self-oiling ring type (§ 189), and carbon brushes are used.

* 187. JACKSON OVERTYPE MACHINE. This dynamo (Fig. 210) is made by P. R. Jackson & Co., in eleven sizes, ranging from 1 to 40 units (*i.e.* 1 to 40 kilowatts). The magnet cores and bed-plate are cast in one piece, and are of mild steel. The pole-pieces are also of cast steel, and are bolted as shown to the tops of the magnet cores. They can thus be easily removed for the examination or withdrawal of the armature, or for the removal of the field-magnet coils. The armature is drum-wound. The commutator is self-contained, it being built up on a cast-iron sleeve, with rings and nuts of wrought steel, this sleeve being keyed to the shaft. Thus a fresh commutator can soon be put on when necessary. The field-magnet coils are wound on collapsible frames (or "formers") of sheet steel with hardwood ends or "cheeks," and the coils can be easily removed therefrom. The terminal blocks are mounted on the coil frames, so that beyond the withdrawal of a copper rod which connects the two coils, and of the ends of the leads from the brushes, no breaking of connections is necessary in dismantling the machine.

The bearings are self-oiling, a *fixed* collar on the shaft dipping into the oil and throwing it up into a "gallery," whence it runs into the bearing.

The nomenclature adopted by this firm to distinguish between the various types of machines built by them, is instructive, and is as follows :—

Type.

O/D (overtype with drum armature).
C/D (centraltype " ").
U/D (undertype " ").

O/G (overtype with gramme or ring armature).
C/G (centraltype " " ").
U/G (undertype " " ").

O/B (overtype with bar armature).
C/B (centraltype " ").
U/B (undertype " ").

In addition to the above the letters *W*, *B* and *P* are used to signify wire-wound, bar-wound, and Pacinotti or slotted core armatures respectively, while *M* denotes a multipolar machine.

The difference between over- and under-type machines was explained in § 180. A *bar armature* is a drum armature with "coils" formed of rigid conductor (see § 172).

188. MATHER & PLATT'S DYNAMOS. These are of three chief types—the Manchester, the Edison-Hopkinson, and the Multipolar.

The MANCHESTER MACHINE (Fig. 211). This is a

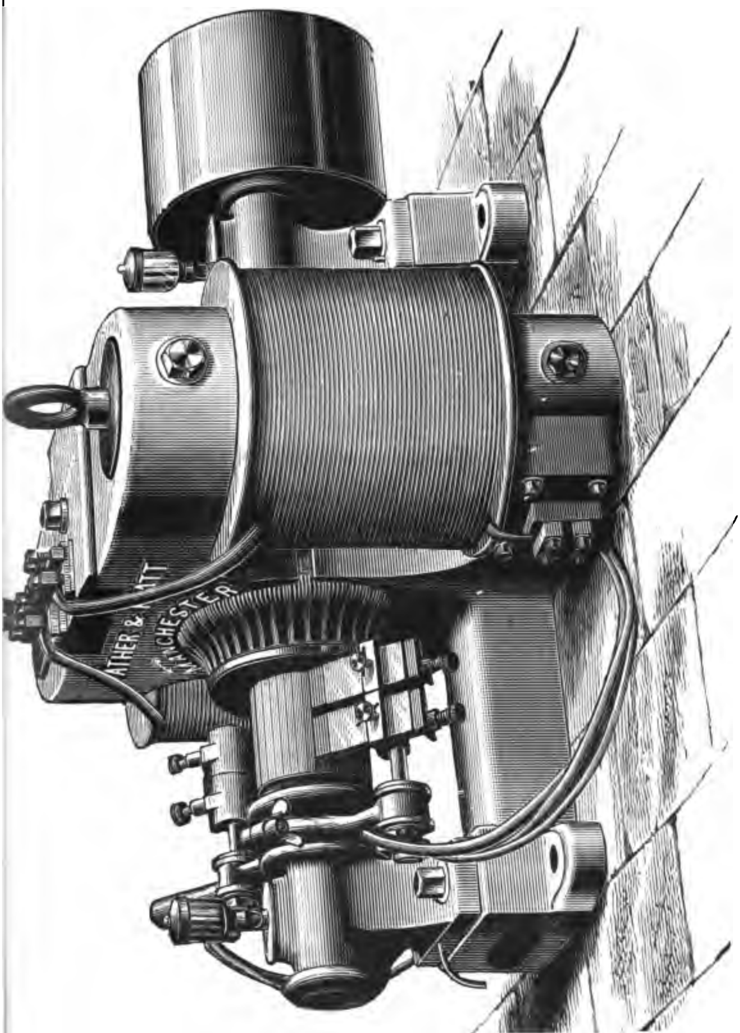


Fig. 211. Manchester Machine.

two-pole double-magnet or centraltype machine, the wrought iron F.M. cores being circular in section. At the bottom these are turned to fit into side arms on the bed-plate (which is somewhat in the shape of a cross), where they are secured by set screws: while at the top they are similarly fitted into a cast-iron yoke, which also forms the upper pole-piece, the lower one being on the bed-plate. A section of the field magnets is given in Fig. 171A. The armature is of the gramme ring type.

When employed as motors these machines are provided with carbon brushes. In the later machines self-oiling or ring bearings are used instead of the ordinary lubricators seen in the figure. Such bearings are described in § 189.

The Edison-Hopkinson Machine (Fig. 212). The Edison-Hopkinson machine embodies the late Dr. John Hopkinson's improvement upon the original type of Edison dynamo. The improvement consisted principally in substituting single F.M. cores for multiple cores, and in shortening the same, as well as increasing their thickness and that of the yoke. Each magnet limb, together with its pole-piece, is formed of a single forging of wrought iron, or a steel casting, as the case may be; the field coils being wound on removable spools. The pole-pieces are separated from the bed-plate by cast brass feet or pedestals, on which the magnet stands. This lessens the leakage of lines through the bed-plate. A section of the F.M. is shown in Fig. 169A. The armature is drum-wound, its con-

ductors being square in section, and covered with insulating tape. This is so for the reason that wire of square section packs more closely round the core

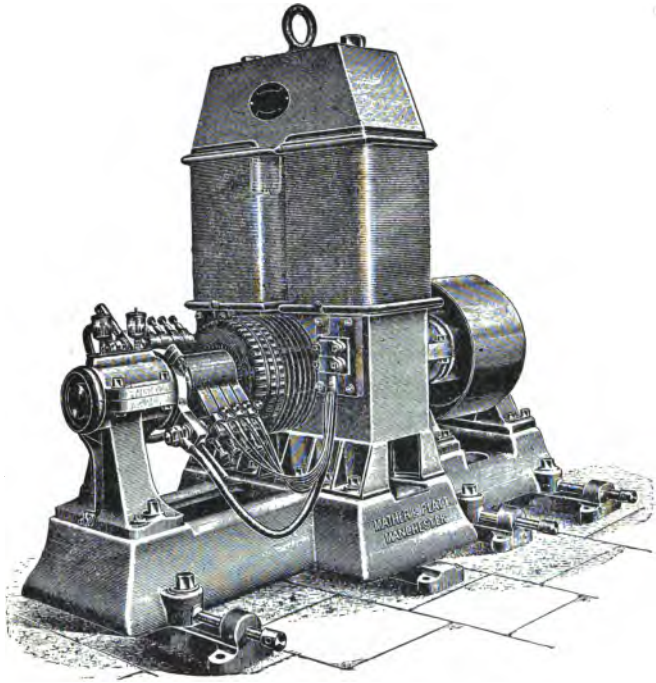


Fig. 212. The Edison-Hopkinson Machine.

than wire of circular section. The brushes are of copper gauze and are held in polished brass holders, which are not only separately adjustable, but are also separately connected to the terminal blocks on

the pole-pieces; there being also the usual connection from the brush-holder bar. The old-fashioned lubricators seen in the figure are now discarded in favour of ring lubricators (§ 189).

The MULTIPOLAR MACHINE. The Edison-Hopkinson machine is made for larger outputs than the Manchester type of dynamo; while for still heavier work the form now under consideration is employed, the largest standard sizes of this kind having an output of 750 electrical horse-power.

The range of output of the three classes is as follows —

	Kilowatts.
Manchester	4 to 24
Edison-Hopkinson . . .	24 to 170
Multipolar	20 to 750

The latter have 4, 6, 8, or 10 poles according to size.

Fig. 213 shows a four-pole machine arranged for rope-driving, the pulley being grooved to take eight ropes. The cast steel field-magnet frame is made in halves, each of which carries two poles, the lower having two strong brackets cast on it at each side to enable it to be bolted to the bed-frame. The armature is of the slotted drum type, the conductors being carefully insulated and completely embedded in the slots. The machine not being cross-connected (§ 173), four sets of brushes are used. The figure shows the machine fitted with gauze brushes, but carbon ones are now always used. The brush-holder bars are

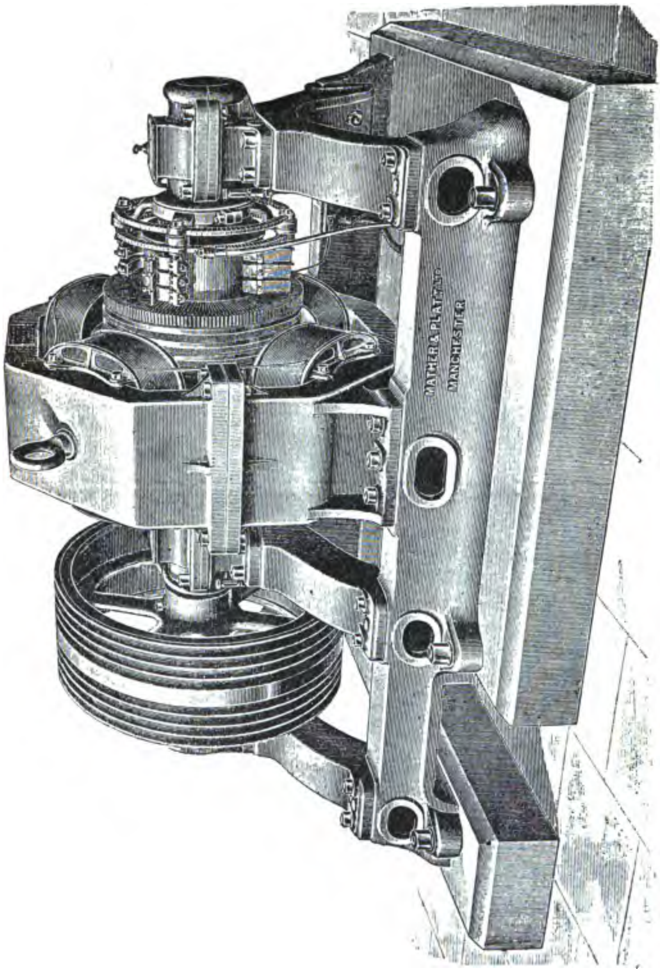


Fig. 213. Mather & Platt's Four-pole Machine.

mounted on insulated rings, the whole arrangement being adjustable by means of a hand-wheel. The bearings are of the self-oiling type, and by the side of each is fitted a glass gauge to indicate the height of the oil in the reservoir. Two of these gauges may be discerned in the figure. The smaller machines of this class have two bearings only.

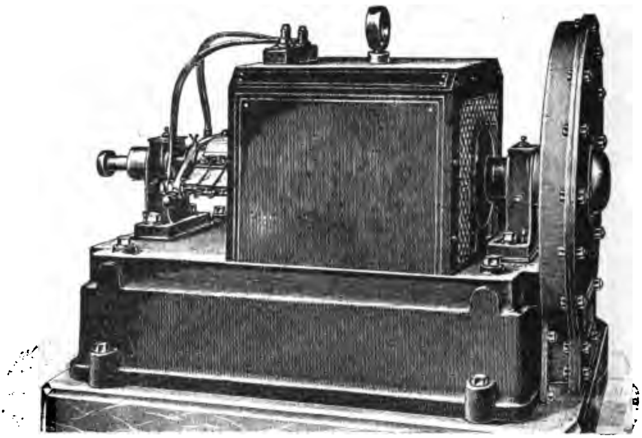


Fig. 214. Lahmeyer Dynamo driven by Turbine.

* 189. LAHMEYER MACHINES. Fig. 214 shows a 60-H.P. two-pole machine as built by Messrs. Garbe, Lahmeyer & Co. It is coupled direct to a turbine, for driving by water power. Figs. 215 and 216 show this type of machine in part elevation and part section, the former being a side view, and the latter a front view. *P* (Fig. 216) is one of the poles, and *C* one of the coils.

The section of the F.M. is more simply shown in Fig. 169F. One advantage of this type of F.M. (which in this case is of cast iron, in one piece), is that there is an entire absence of external magnetic field, especially if the slinging eye *S* is removed and replaced by a brass bolt, as may be done when the dynamo is in position. Another feature of the machine is that its armature *A*, which is drum-wound, is well protected from injury by means of zinc gratings, *Z Z Z*, at each end. The machine is mounted on *slide rails R R*, and by means of bolts and set screws (*S S*) at each end may be adjusted to a nicety with regard to its driving belt. Holding-down bolts *B*, at each corner, clamp the machine firmly to the rails when in the right position. This method of mounting is adopted, when required, with machines of any make.

The *self-oiling bearings*, which are now used in nearly all modern machines, should be specially noted. On each end of the shaft hangs a zinc ring *r*, whose internal diameter is about twice that of the shaft. The top half of the bearing is slotted, so that the ring hangs directly on the shaft. The lower two-thirds of the ring dip in an oil-bath *O*, and as the shaft revolves, the ring is slowly turned and feeds up oil to the top of the shaft. The oil then distributes itself along the bearing, which latter is made extra long so as to minimise the pressure on it, and allow the oil to travel wherever necessary. Such bearings are sometimes called *ring bearings*. The ridge or *oil thrower r′* throws off superfluous oil by centrifugal force, and so pre-

vents it getting to the commutator or end connections of the armature; the oil running back into the oil-bath *O*. Each oil-bath has a small cock attached to it (Fig. 214), whereby the oil may be drawn off when necessary, for filtration.

Z' (Figs. 215 and 216) is the zinc face of one of the coils. This has a dent on its inner side (shown be-

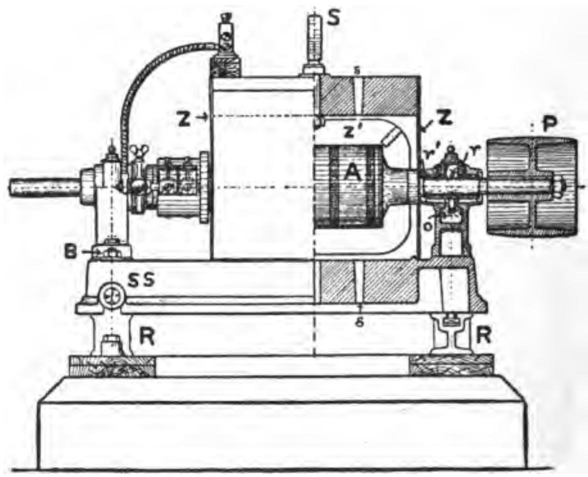


Fig. 215. Lahmeyer Machine. (Side elevation: part section.)

tween *Z* and *Z'* in Fig. 215), so that the inside end of the coil may be brought out without being in the way of the upper layers of wire.

Ventilation of the machines is provided for by means of slots in the top and bottom of the frame; two of which, *s s*, can be seen in Fig. 215. As there shown, the slots appear to be directly above and beneath the

armature, but in reality they are on one side, so that in the case of the upper slots, anything dropping through would fall to one side of, not on the armature. The circulation of air being upwards, there is little or no tendency for dust to enter. When the machine is being cleaned, these holes should be closed with wooden

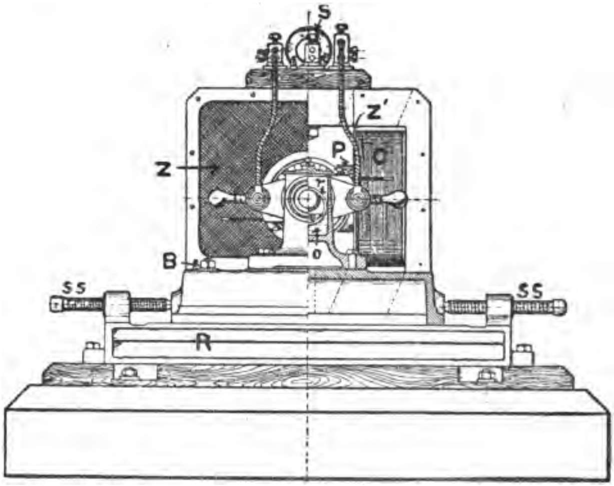


Fig. 216. Lahmeyer Machine. (End elevation: part section.)

plugs. The cast-iron pulley P is slotted on to the shaft, and held in place by a feather or key and nut.

The terminal board on the top of the compound machine carries four terminals, three large and one small (Fig. 216). To the two outer ones the armature is joined up. The shunt F.M. coils are connected to the second and fourth; and the series F.M. coils to the

third and fourth (starting from the left); the first and third being the main terminals, from which the cables to the outer circuit proceed. To the first and second terminals is connected an adjustable resistance which

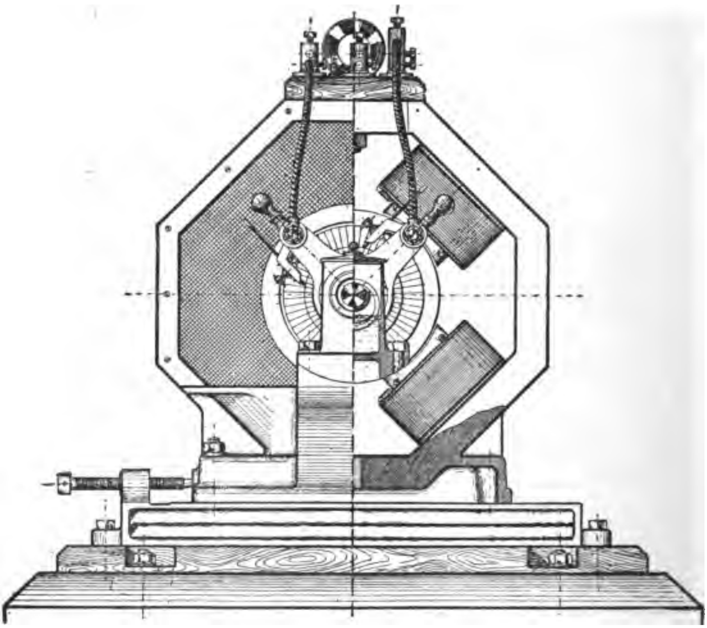


Fig. 217. Four-pole Lahmeyer Machine.

is thereby put in the shunt F.M. circuit. Series and shunt-wound machines have three terminals. The connection of the regulating resistance in all three cases will be illustrated and described in Chap. X., in dealing with the regulation of dynamos.

Sections of the F.Ms. of four- and six-pole Lahmeyer machines are shown in Fig. 173. Fig. 217 illustrates a four-pole machine in part elevation and part section. The armature is practically the same as that used in two-pole dynamos, except that it is cross-connected (§ 173), and for that reason the brushes are set 90° apart as shown. The machine illustrated is compound-wound, and for convenience in connecting the regulating resistance, four terminals are provided, as explained in connection with the two-pole type.

It may be mentioned that there are other machines bearing the name of Lahmeyer.

190. JOHNSON & PHILLIPS' MACHINES. Messrs. Johnson & Phillips were among the first manufacturers to employ the overtype form of field magnet, this having been originally designed for them by Mr. Kapp; hence such is sometimes referred to as the *Kapp type.*

Fig. 218 represents the latest form of overtype bi-polar machine manufactured by this firm. Each magnet limb and pole-piece is formed of a single solid slab of wrought iron or steel bolted to the cast-iron bed-plate. The middle of the bed-plate, being solid, forms the yoke, and the cross section of this part is larger than that of either of the limbs to make up for the greater magnetic resistance of cast iron. The armatures of these machines are of the drum type, and the cores are built up of well annealed charcoal-iron plates keyed direct on to the shaft.

Four or more fibre *driving horns* or *keys*, according

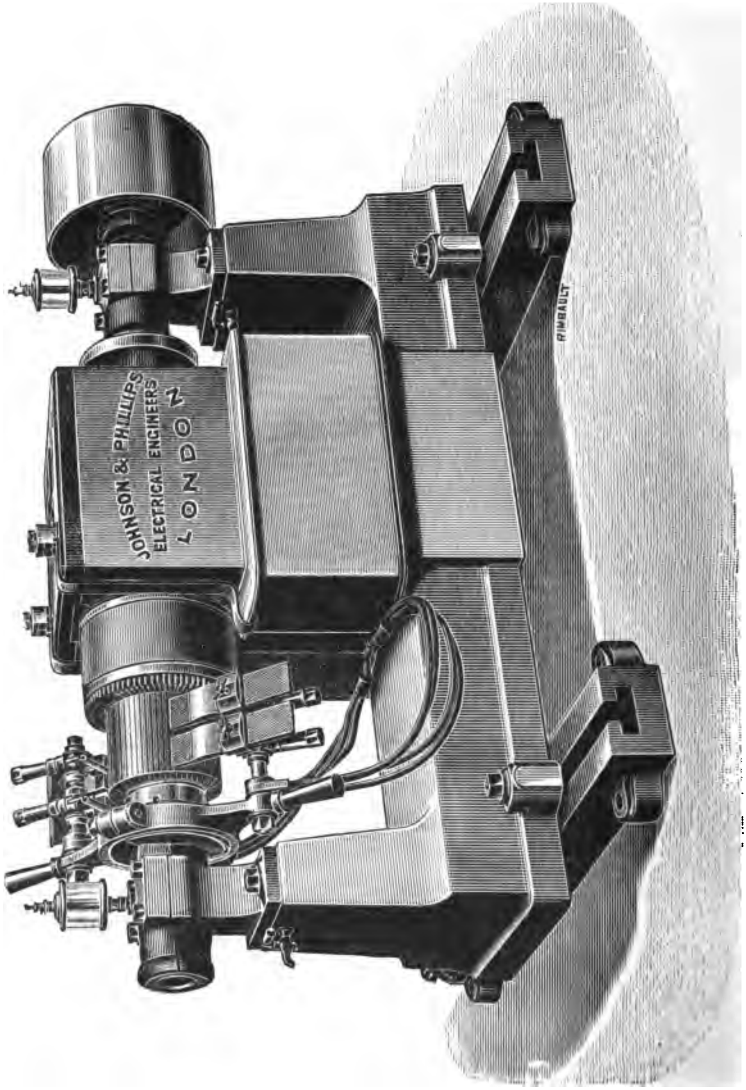


Fig. 218. Johnson & Phillips' Overtype Machine.

to the size of machine, are fixed in slots cut longitudinally on the circumference of the core. These "horns" or ridges serve to drive the conductors, the armature being smooth cored (§ 181). Were it not

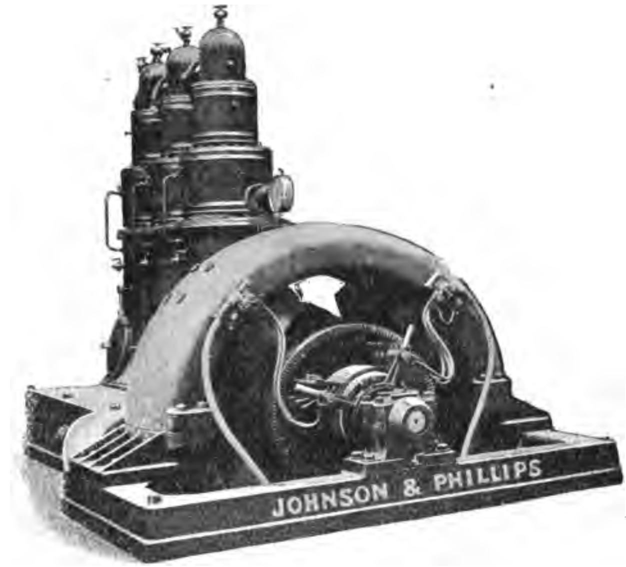


Fig. 219. Johnson & Phillips' 4-pole Generator coupled to a Willans Engine.

for these, the conductors would have no rigid fixing to the core, and would be liable to slip thereon under great strain, the tendency of the magnetic field of a dynamo being to resist the rotation of the conductors in which E.M.F. is being generated. The conductors

are of high conductivity copper, and in the case of the larger machines are stranded to minimise the loss due to eddy currents.

In the figure the machine is shown as mounted on slide rails, the use of which is explained in § 189. It will also be noticed that this particular machine is fitted with outside lubricators.

For outputs exceeding fifteen or twenty kilowatts, this firm, like most others, adopt the four-pole or multipolar form of field magnet. The appended figure (219) illustrates a four-pole generator coupled to a Willans engine. The magnet frame is in halves, each of which supports a pair of poles. The magnet cores are of cast steel and are bolted to the frame, the latter being of cast iron or steel according to circumstances. The field coils are wound on removable bobbins.

The armature is of the slotted type, and is built up of well annealed charcoal-iron stampings, spaces being left at intervals between the plates to allow of thorough ventilation. The armature coils, which are former-wound (§ 184), are placed in the slots and are afterwards bound over with bands of German silver wire insulated from the coils by strips of mica, these acting as binding wires (§ 183). The coils are cross-connected, there being two sets of brushes only.

The commutator is composed of hard-drawn copper segments insulated from one another by mica. The segments are congregated on a massive cast-iron sleeve, and are securely bound together by a steel clamping ring, the sleeve and the clamping ring being insulated

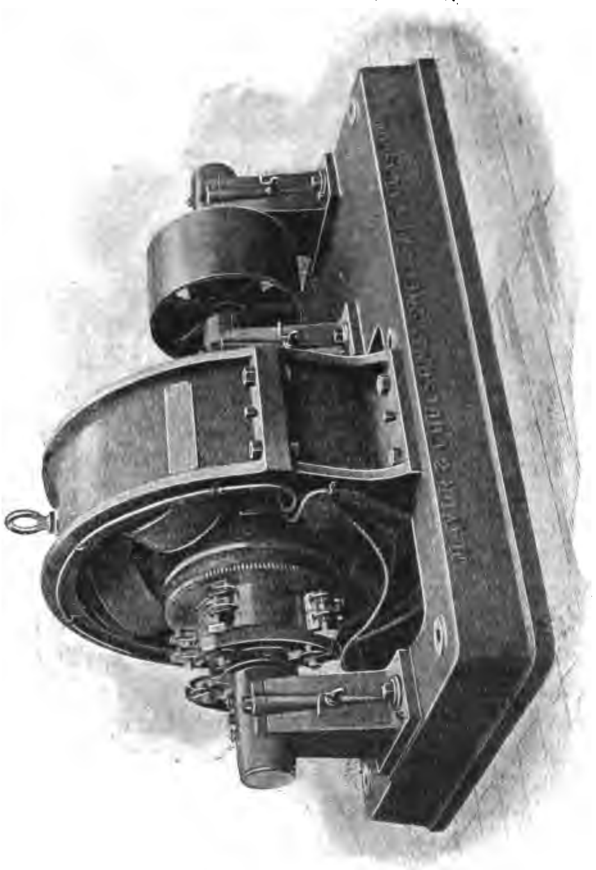


Fig. 220. Mavor and Coulson's Four-pole Machine.

from them by thick moulded mica rings. The brushes are of either copper or carbon as desired.

These machines are provided with self-oiling bearings, the lubrication being effected by rings resting on and revolving with the shaft, and dipping into a well containing oil in the pedestal. Such bearings are more fully described in § 189.

191. MAVOR & COULSON'S MULTIPOLAR MACHINE. The machine illustrated in Fig. 220, a three-bearing multipolar machine for separate driving, is made in sizes giving from 39 up to 200 K.W. output, at speeds varying from 700 to 350 revolutions per minute according to output. Larger sizes are always direct-coupled to the engine, and are made for speeds varying from 350 down to 90 revolutions per minute. The machine in the figure has four poles, but those giving above 80 K.W. output have six. The machines for direct-coupling are essentially the same as that shown in the figure, except that the bed-plate is incorporated with that of the engine.

The armatures of these machines are of the slotted-core type, drum wound, so that a positive drive is secured to the conductors by the teeth. They are built up of thin discs of soft charcoal-iron insulated with varnish and mounted on a cast-iron spider, which is keyed to the shaft, but is detachable therefrom. This spider also carries the commutator. The conductors, which are in the form of bars, are insulated from each other by tape and from the armature core by pressspahn paper.[1] They are fitted in the slots,

[1] *Pressspahn* (German *press*, pressed; *spahn*, wood-shaving) is, as its name indicates, a material made of compressed wood

and on the top of each slot is placed a thin strip of hard wood, which serves to keep the conductor in place. The whole armature is bound by bands made up of several turns of tinned steel binding-wire securely soldered together and insulated from the core by mica.

The steel magnets are cast in two pieces and bolted together on the horizontal diameter. The top half can be lifted off, and the armature easily inspected and removed if necessary. The bottom half is bolted to the bed-plate by bolts passing through feet cast on the side of it. The poles are cast solid with the yokes, and are provided with pole-pieces, which are fixed to them by sunk bolts. By removing the pole-pieces, the magnet coils, which are wound on sheet metal formers, can be slipped off.

The bearings are self-oiling and self-aligning, and the oil can be drawn off by the oil cocks shown. The shaft is provided with *oil throwers*, or ridges, inside the bearings, from which the oil is projected by centrifugal force, so that none can flow along the shaft to either the core or the commutator. These oil throwers are common to most machines, and can be plainly discerned in Figs. 196 and 215.

The commutator is carried on a cast-iron sleeve fitted to a projection of the hub carrying the armature core, and directly bolted to it. The joints of the armature conductors with the commutator lugs

fibre. It is cheaper than vulcanite and more durable than pasteboard.

are soldered by being dipped in a trough of molten metal, thus ensuring the thorough heating and "floating" of the same. The insulation of the commutator is of mica and micanite throughout. The brushes used are of carbon, which enables the machine to run sparklessly through a large range of load after they have been properly bedded and the right lead obtained. The brush-holders are fixed to gun-metal spindles carried by a cast-iron rocker, which runs in a groove at the end of the bearing, as shown in the illustration. The adjustment is got by means of a screw and hand-wheel, which however cannot be seen in the figure.

The brush spindles or holder bars of similar poles are connected together by copper collecting straps, and from these the current is carried to the main terminals.

The machines are made both shunt and compound wound.

192. SIEMENS' FOUR-POLE MACHINE (Fig. 221). The cast steel field-frame of this machine is circular in shape, and is made in two parts, the lower one being supported by the bed-frame. The magnet poles are of laminated steel. The armature is cross-connected, and its commutator is unusually large in diameter. The brushes are of carbon, and are contained in aluminium holders, each of which is separately connected to the supporting bar by means of a flexible lead. It should be noticed that there are no less than eight brushes on each pole of the machine illustrated in the figure.

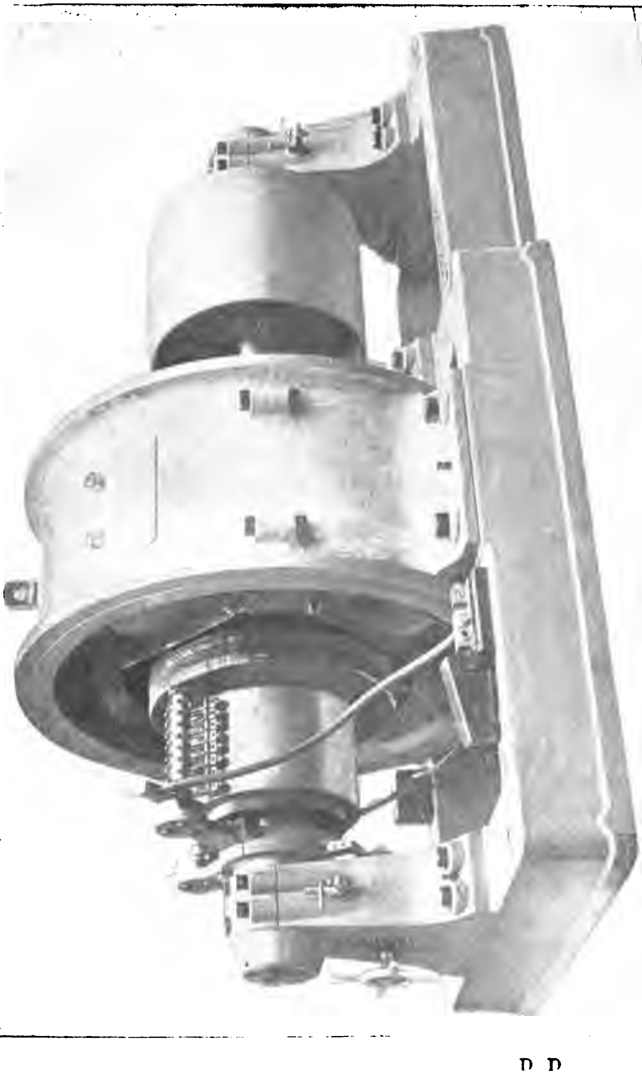


Fig. 221. Siemens' Four-pole Machine.

The star hand wheel on the front of the left-hand pedestal carries a pinion at the other end of its shaft; this engaging in a toothed sector on the rocker. By this means the lead of the brushes is adjusted.

The terminals are mounted on insulating blocks on the bed-frame, and are provided with covers. The bearings are self-oiling, and each is fitted with a gauge glass to show the height of the oil, and with a drain-cock.

193. LAURENCE, SCOTT & CO.'S SIX-POLE MACHINE. Fig. 222 illustrates a six-pole direct-current generator for rope driving, the pulley being grooved for nine ropes. As is usual in large machines, there are three bearings, these being of the self-oiling type, with oil level indicator glasses and drain cocks. The cast-iron bed-plate is in one piece, and the bearings are on pedestals bolted thereto.

The magnet cores and yoke are of special cast steel, the yoke ring being in two halves, so that the upper part can be lifted to get at the armature. The latter is of the slotted drum type, and is well ventilated.

The six sets of brushes are mounted on a six-armed rocker, the position of which may be adjusted by means of the hand-wheel seen above the right-hand bearing. The brushes are of carbon, and there are four to each set, the sets being connected alternately with the positive and negative terminals of the dynamo. Two of the connecting straps for this purpose can be plainly discerned in the figure.

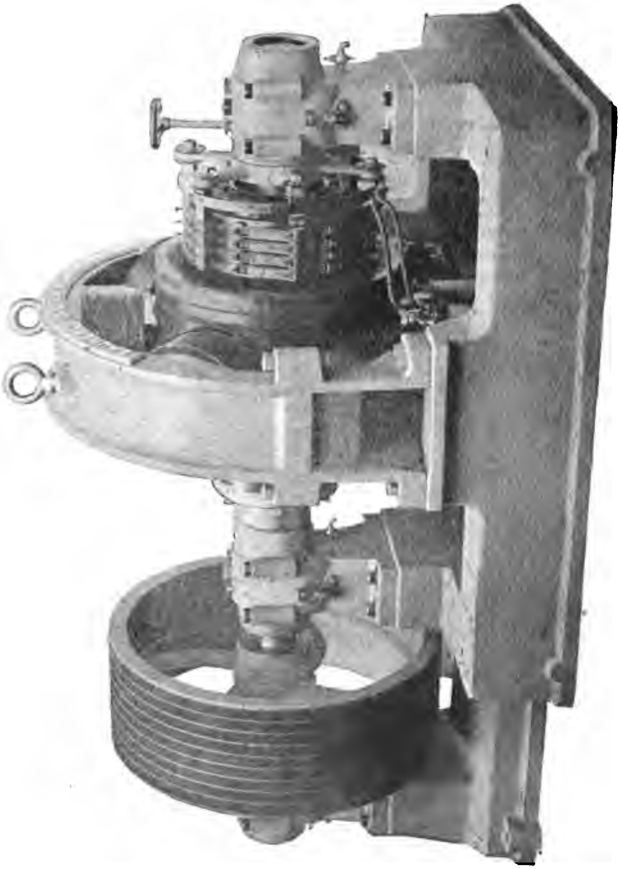


Fig. 222. Laurence, Scott & Co.'s Six-pole Machine.

Fig. 222A shows the field-frame, armature, and right-hand bearing and rocker apart.

It was mentioned in § 173 that by cross-connection the current could be collected from a multipolar

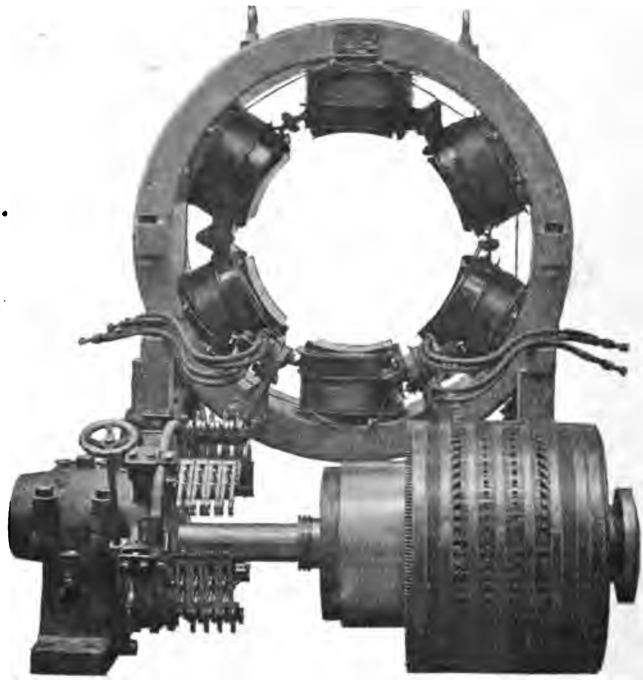


Fig. 222A. Laurence, Scott & Co.'s Six-pole Machine (Armature and Field-frame apart).

machine with two sets of brushes only. Cross-connection, however, is seldom resorted to in machines for large outputs, as the current density is so great

that if the number of points of commutation were reduced to two, the commutator would have to be made much longer in order to give sufficient collecting surface. In other words, the bearing surface of the brushes must be proportional to the density of the current to be collected. And the greater the latter the longer must be the commutator.

194. PHŒNIX FOUR-POLE MACHINE (Fig. 223). The illustration on page 406 represents one of the latest open-type machines made by the Phœnix Dynamo Manufacturing Company. The term *open-type* is used to distinguish ordinary machines from those which are more or less cased-in or enclosed (*enclosed type*), the latter construction being chiefly used for motors (Chap. XIII.). The machine is of the four-pole type with slotted armature and barrel winding (§ 183), each coil being separately formed and thoroughly insulated before being mounted on the core. The core-slots are lined with troughs of flexible mica, pressspahn, and oiled linen; while the end-plates are similarly insulated. The core discs are of charcoal iron ·025 of an inch thick, and are insulated with special varnish. Four air spaces are left in the core and the whole armature is thus well ventilated. Carbon brushes are used. Each main terminal is placed in a small insulating box fitted on the bed-plate, as seen in the figure.

The yoke and pole-pieces are of cast steel, and are provided with steel pole tips, which keep the field-coils in place. The latter are "former" shaped, and

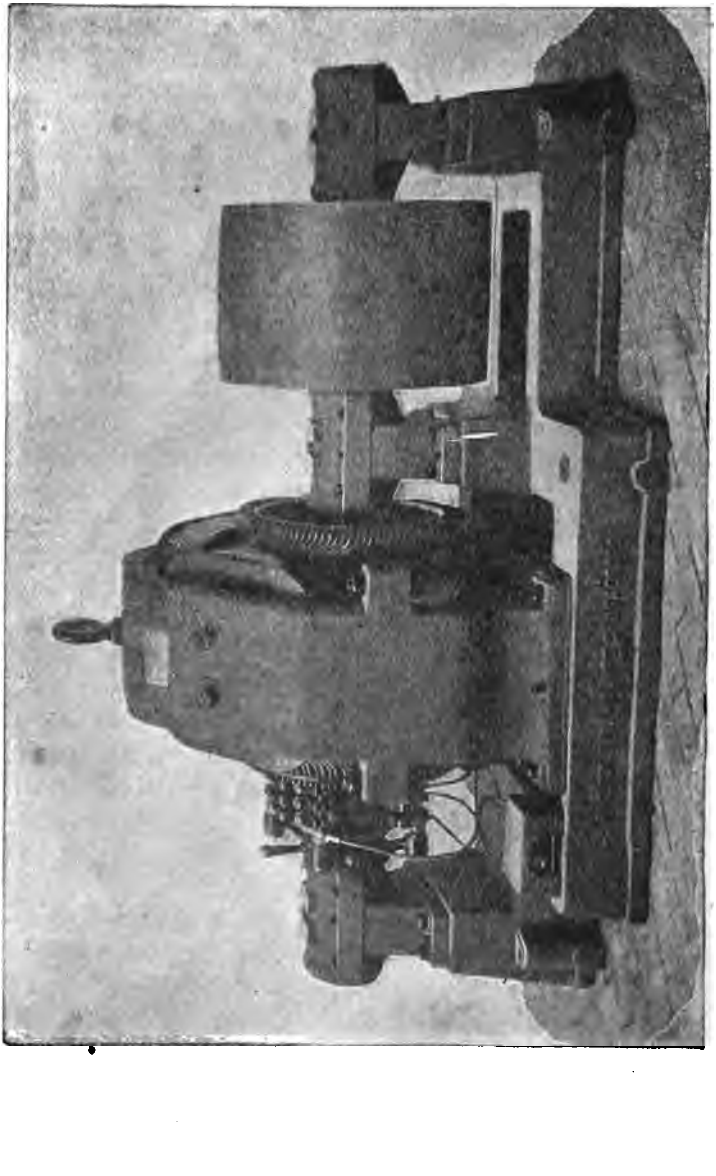


Fig. 223. Phœnix Four-pole Machine.

are thoroughly insulated with mica and tape, thin wooden flanges being placed at each end for mechanical protection. The shaft is thicker than is usual, and runs in bearings formed of swivelling or self-aligning brass bushes lined with anti-friction metal, the lubrication of each being effected by two rings on the self-oiling principle (§ 189). There are three bearings, and the pulley measures 23 inches in diameter with a 15-inch face.

The type of machine illustrated is the Phœnix Co.'s usual design for open generators and motors; those for outputs above 100 K.W. having six poles.

195. Gas-Driven Multipolar Generator (Fig. 224). This dynamo is one of a series designed by the British Thomson-Houston Co. for coupling direct to a gas engine; and it is capable of yielding an output of 10¾ K.W. at 110 volts, the machine being compound wound to give this pressure at all loads. The engine shown in the figure is one of the Crossley type.

The dynamo is an eight-pole one, and it is built on the same general lines as the standard machines supplied by the above-named Company for direct steam driving. The use of the multipolar form renders the machine very compact for a given output.

The field-frame, which is divided horizontally to allow of easy access to the armature, is mounted on an extension of the engine bed, which extension also supports the outer bearing. This field-frame carries the eight poles, four on each half; and the pole cores,

together with their spools or bobbins, are individually removable therefrom.

The magnet bobbin on each pole is held in place by

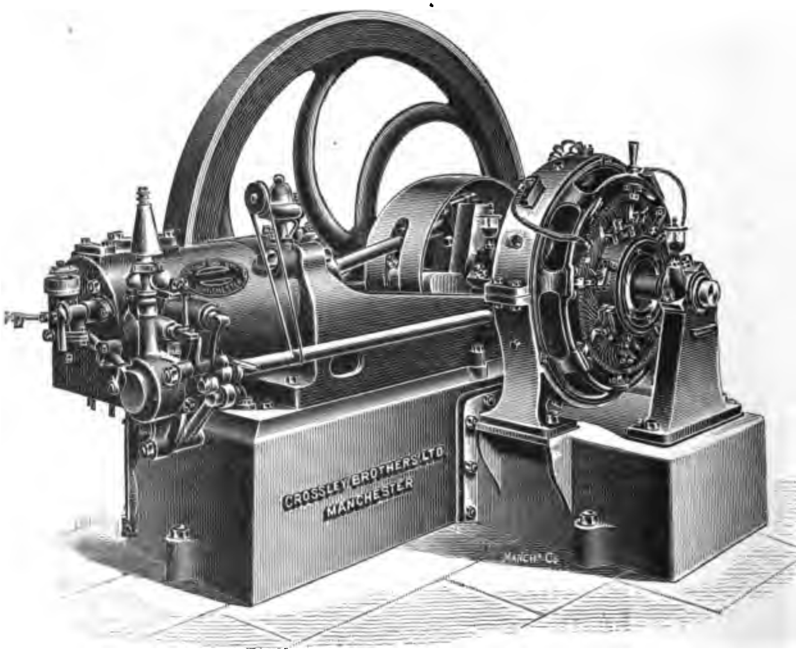


Fig. 224. British Thomson-Houston Multipolar Generator coupled to a Crossley Gas Engine.

a projecting pole-piece, but it may easily be removed from the pole when this has been unbolted from the magnet ring.

The armature core is built up of soft steel lamina-

tions, each lamination being insulated with a coating of Japan varnish, in order to retard the setting up of eddy currents. The armature is of the slot-wound type, the winding itself consisting of interchangeable former-wound coils. The end-connections of the winding are carried on extensions from the armature spider.

The commutator is built up of hard-drawn copper segments insulated with a suitable quality of mica to ensure uniform wear, and is carried on a second spider fixed to the armature spider. The segments are held in such a way as to allow of practically their full depth being used for turning down when the commutator requires trueing up.

The machine is equipped with carbon brushes and brush-holders of special design. There are eight sets of brushes (two in each set), and these are connected alternately to the + and − poles of the dynamo. The brush-holder bars are mounted on, but insulated from, a circular rocking frame, which may be rotated by the handle seen in the figure. The gear for this is mounted on the magnet frame. The bearings are fitted with ordinary sight-feed lubricators.

196. Brush Arc Dynamo (Fig. 225). A section of the F.Ms. of this machine is shown at Fig. 172A, and from that it would appear as if the dynamo was rightly described as a four-pole machine. It certainly has four pole-pieces, but as the opposite ones are of similar polarity, it must be considered as a two-pole machine. The cores of the F.Ms. are oblong in section, and are bolted to the cast-iron bearing standards

which form their yokes. The armature core is built up of iron ribbon wound on a central iron ring. This is shown in Fig. 226, where *A′* is the iron foundation ring, upon which is coiled the thin soft iron ribbon or strip *B*. Between each layer of this ribbon are placed H-shaped stampings of soft-iron *H*, which, together with the ribbon, are held in place by bolts *r*, which pass through the ribbon *B*, stampings *H*, and foundation ring *A′*. These H-pieces form spaces in which

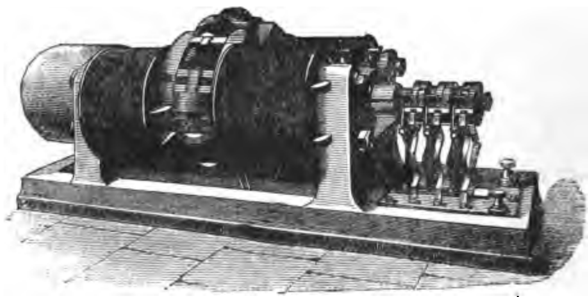


Fig. 225. Brush Arc Dynamo.

the coils are wound. The armature is an open coil one (§ 174), and a special *compound commutator* is used, which keeps the least active coils in parallel with themselves, and in series with the most active coils; while it successively open-circuits the several coils as they pass through the neutral regions of the field (Fig. 228). The machine is series wound, and it is used to supply current to arc lamps in series, for which purpose a constant current is necessary (§ 179).

Fig. 225 represents a machine with twelve coils and three commutators; but for the purposes of description we shall consider one having eight coils and two commutators. Fig. 227 represents the core, carrying eight coils. Opposite coils are joined in series after the manner shown in Fig. 183, the free ends of each pair being connectedto separate segments of the commutator. For clearness, the connection between opposite coils is not

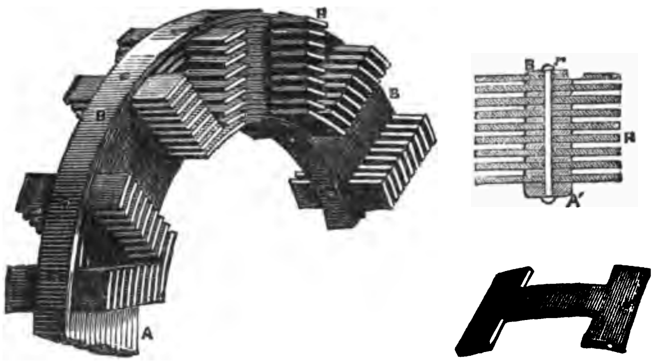


Fig. 226. Brush Arc Dynamo (Armature Core).

shown; but it will be understood that the two coils of each pair, A A′, B B′, C C′, and D D′, are always in series with each other, and therefore may be practically considered as one coil. When these four pairs of coils are revolving in the magnetic field between N. and S., it is clear that at any given moment only one pair can be in the position of greatest activity, and only one pair in the position of least activity, while the other two pairs will be in an intermediate

position. Thus in Fig. 227, A A′ are in the position of maximum activity, C C′ are least active, while B B′ and D D′ are in the intermediate positions. In an eight-coil machine, such as is represented in the diagram, there are two pairs of brushes and two commutators.

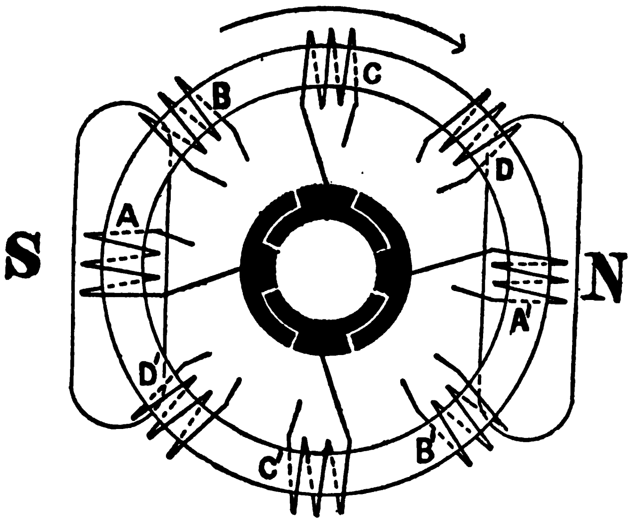


Fig. 227. Brush Arc Dynamo (Diagram of Connections of Armature Coils).

Two pairs of coils, A A′ and C C′, are connected to one commutator, and the other two pairs to the other commutator. In Fig. 227 only one commutator is shown, the other being behind. The commutators and brushes are so arranged that one collects the current from the coils in the best position, while the other

collects from the two pairs in the intermediate positions, the pair in the inactive position being cut out of circuit. Each pair of coils is successively in the best, intermediate, inactive, and intermediate positions.

The two pairs of brushes are joined in series (Fig. 229), and the commutators are so constructed that at

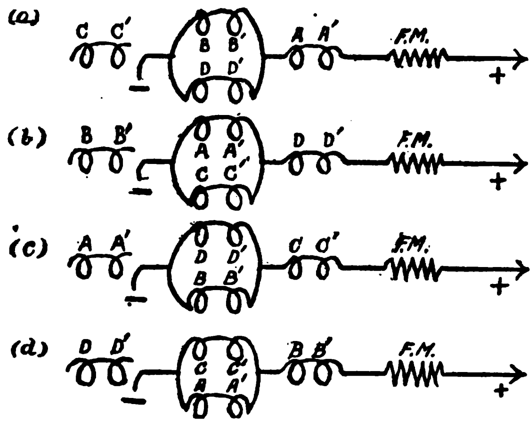


Fig. 228. Brush Arc Dynamo (Diagram of Connections of Armature Coils).

any instant the two pairs of coils that happen to be in the intermediate position are connected in parallel with each other, and in series with the most active pair, the least active pair being temporarily disconnected from the circuit. Thus with the coils in the position shown in Fig. 227 the circuit is as shown in Fig. 228*a*. When the armature has turned 45°, C C′

and A A′ will have entered the position of intermediate activity, B B′ will be inactive, and D D′ will be most active. A A′ and C C′ are therefore temporarily joined in parallel with each other, and in series with D D′, while B B′ are cut out altogether. This is depicted in Fig. 228*b*. Figs. 228*c* and *d* show the

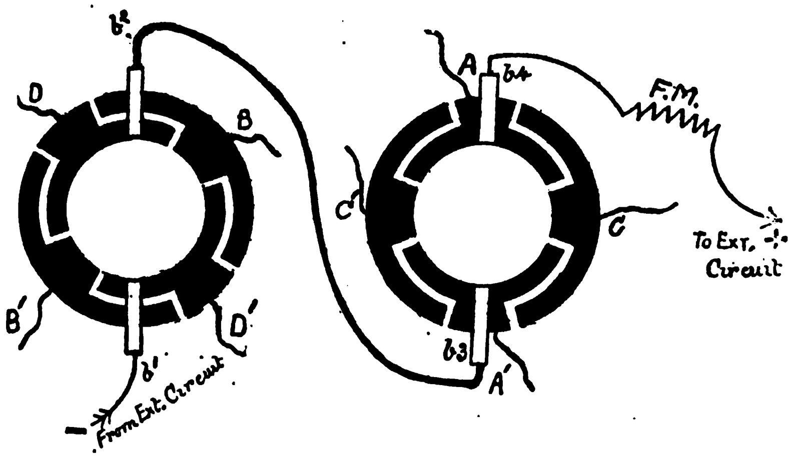


Fig. 229. Brush Arc Dynamo (Diagram of Commutator Connections).

arrangement of the coils when the armature has travelled 90° and 135° respectively from the position shown in Fig. 227. As will be gathered from Fig. 228, the machine is series wound, *F.M.* being the field coil.

Fig. 229 gives a diagram of the two commutators, which are of peculiar construction. In reality they

are placed one behind the other on the shaft (Fig. 225), but in Fig. 229 they are shown side by side for convenience. b^1 is the – brush, b^2 and b^3 are connected together, while b^4 is the + brush; whence the current passes through the F.Ms. and external circuit. In the position shown, the two pairs of coils B B′ and D D′ are connected in parallel by the brushes b^1 and b^2, and in series through brush b^3 with A A′, while C C′ are cut out altogether.

The largest machines of this type will supply as many as 55 or 60 arc lamps in series, and give therefore a pressure of nearly 3,000 volts.

These machines are not so much used as they were formerly, as arc lighting is now usually effected from the low-tension parallel mains laid for general house service (Chap. XVII.). But wherever it is required to serve a number of arc lamps on a long series line, machines of this type are preferable because of the smallness of the conductor, and the simplicity of the circuit arrangements. The usual arc lamp current is about 10 amperes, and this can be carried by a conductor about $\frac{1}{8}$th inch in diameter if the lamps are arranged in series.

The subject of arc lamps and their connection in circuit is fully dealt with in the Author's *Electric Wiring, Fittings, Switches, and Lamps*, which is a supplement to the present work.

CHAPTER IX.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Distinguish between *undertype*, *overtype*, and *central-type* dynamos, and say which you think the best, and why.

2. Given the two wires coming from the poles of a continuous current dynamo, how can you tell which is positive and which negative? [Ord. 1891.]

*3. *Define:* driving horn, unit dynamo, Pacinotti teeth, distance piece.

4. Give a clear and careful sectional sketch of a drum armature.

*5. Distinguish between smooth-core and slotted-core armatures, and enumerate the advantages of the latter.

*6. Why is the use of single brushes not good?

7. Distinguish between belt-driving, direct-driving, and rope-driving: which do you consider the best for slow speeds and high speeds, and why?

8. Give a hand sketch to full size of a bearing for the shaft of an armature: diameter of shaft, $1\frac{3}{4}$ inches; length of bearing, 6 inches. [Ord. 1893.]

9. Explain various methods of lubricating bearings.

10. Mention those machines in which the armature can be conveniently got without removing it from its bearings.

11. How are binding wires applied to an armature, of what are they made, and why are they used?

12. What is a self-aligning bearing?

13. Explain the advantages of the Eickemeyer method of winding drum armatures.

14. In what ways may the different kinds of dynamo be classified?

15. Is there any advantage in having an armature large in diameter?

16. Give a sketch of the connections to the terminal board of a compound-wound Lahmeyer machine.

*17. Tabulate all the machines mentioned in this chapter under the following headings:—type F.M., no. of poles, kind of armature, type of bearing, method of lubrication, special points; and give in each case a section of the magnetic circuit, showing which parts are of wrought and which of cast iron.

18. What are the advantages of four-pole over two-pole machines?

19. What peculiarities are there in the design of a dynamo for supplying arc lamps in series, at (say) 3,000 volts? [Ord. 1895.]

20. Explain why armatures of large diameter are generally necessary in a high voltage direct-current machine.

21. Considering one pair of coils *AA′* of the brush arc dynamo, show by sketches the different ways in which it is joined up with the other coils, and with the external circuit, during one revolution of the armature: and give reasons.

*22. A drum armature has an invisible contact between two neighbouring armature conductors; how would you localise it? [Prel. 1897.]

[*NOTE.*—VOLUME II. will comprise chapters on the Theory and Working of Dynamos, Alternating Currents, Alternators, Motors, Meters, Accumulators, Transformers, and Central Stations.

It was intended to include in this the already published *Electric Wiring, Fittings, Switches, and Lamps*; but owing to the bulk of the latter, it has now been decided to keep it as a separate and supplementary volume.]

INDEX TO VOLUME I.

N.B.—*The figures refer to the numbered paragraphs.*

LAWS.

RULES.

TABLES.

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T.

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